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Evaluation of Sleep Discipline in
Sustaining Unit Performance



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Evaluation of Sleep Discipline in Sustaining Unit Performance

INTRODUCTION

Continuous operations is defined in U.S. Army Field Manual 22-9 as continuous land combat with some opportunity for sleep, although this sleep may be brief or fragmented. The successful development and application of a doctrine for managing sleep and alertness in continuous operations is essential to success on the future battlefield. The potential technological advantages provided by night vision and electro-optical devices for all weather operations increase the potential for continuous operations.

The Soviet soldier and his unit have planned continuous operations in a 2-3 day surge period with no opportunity to sleep. After the surge, the soldier and his unit are rotated from the action for a period to rest, reorganize, and resupply while another unit conducts the operation. The U.S. Army cannot conduct continuous operations by rotating personnel in shifts (in part because of the inability to rotate crews or teams efficiently). The U.S. Army cannot conduct continuous operations by fighting soldiers and units to exhaustion and replacing them with fresh personnel because of the numerical superiority of the Soviet Union and its allies in men and materiel (WRAIR Technical Report No. BB-87-1).

The combat unit must maintain an efficient balance of sleep and work to sustain high levels of performance in continuous operations. Ideally, every individual would receive adequate sleep to maintain effective performance on a daily basis. This performance must be maintained in all activities during the day. Nominally the amount of sleep necessary to do this depends on the individual and the tasks to be performed. Continuous operations are routinely conducted by U.S. Navy, U.S. Air Force, and U.S. Army aviation units with 6-8 hours of sleep in every 24 hour period.

It is difficult and potentially dangerous to conduct unit level exercises to evaluate the long term impact of continuous operations with different sleep disciplines. Laboratory measurements of effectiveness on experimental tasks do not readily translate into performance of tasks necessary to maintain operational effectiveness. As a step to examine the implication of different sleep disciplines, an effort was undertaken to define, develop, test, and evaluate a methodology to incorporate sleep into the Army Unit Resiliency Analysis (AURA) model.

This study was undertaken to develop a computer simulation algorithm for sleep, to integrate that algorithm into a mission effectiveness model of unit operations, and to test the relationship between different profiles of sleep discipline in terms of unit effectiveness. A sleep reservoir model was adopted and tailored from the methodology used within the Army Unit Resiliency Analysis (AURA) model developed by the U.S. Army Ballistic Research Laboratory (BRL). The coefficients for the reservoir model were determined from a best fit of empirical data gathered by the Walter Reed Army Institute of Research (WRAIR) and model data from the U.S. Army Research Institute (ARI). The AURA model was used to represent the unit, scenario, and sleep patterns that were to be tested to determine unit effectiveness. Within the modeling environment, the unit was forced to operate around the clock with specific periods set aside for sleep. The unit's ability to perform the mission using different sleep disciplines was analytically determined as was the consequences of sleep deprivation.

Following are a few basic characteristics which were used to develop the representation of sleep. People were assumed to have a certain reserve of sleep with a definite limit to the amount of sleep that can effectively be of benefit for future performance. Continuous periods of work depleted the reservoir and sleep replenished the reservoir. For each person and job, there was a function that determined the rate of depletion or "fatigue" and another function that determined the rate of replenishment. As personnel continued to work beyond their normal capabilities, their performance deteriorated and effected their individual effectiveness to do their job. Each job had a different demand on sleep reserves. Jobs that required a high cognitive load used up the sleep reservoir faster than those jobs with a low cognitive load. On average, the reservoir depleted at a rate of 25% per 24 hours of work. The replenishment rate varied from individual to individual. For Phases I and II of the study, it was assumed that for the average person, 6 hours of sleep per day was sufficient to maintain full effectiveness indefinitely (i.e., a rest-work cycle of 6 hours sleep and 18 hours work). In Phase III of the study, a normal distribution of requirements with a mean of 6 hours was combined with the varying work demands to investigate the effects of individual differences on performance and unit effectiveness.

The study itself was conducted in three parts. The first part of the effort was to look at unit effectiveness with set levels of minimum sleep per day. In this particular environment, we did not play individual variations in the sleep balance equation. We looked solely at how the sleep regimens of 7, 6, 4, and 1 hours effected unit effectiveness.

In Phase II, we used the model to determine how many hours of sleep would be necessary to maintain set levels of individual effectiveness, assuming that in certain emergency situations, one might be willing to accept less than optimal performance in order to extend the duration of work without sleep. Individual effectiveness levels of 100%, 80%, 75%, 50% were maintained by arranging a minimal sleep period for each individual whenever performance deteriorated to the criterion level of effectiveness. For each job, we determined the aggregate amount of sleep per day required to maintain the criterion level of effectiveness.

In Phase III, we looked at individual variation as a determinant of the unit sleep requirements. Sleep requirements were specified as a normal distribution with a mean of 6 hours and a standard deviation of three-quarters of an hour. Five sleep regimens were studied that allocated to individuals in the unit 4, 5, 6, 7, and 8 hours of sleep; unit performance was assessed over a period of 20 days under each regimen.

OBJECTIVE

The objective of this study was to determine the relationship between sleep and unit effectiveness using a computer model to simulate unit performance. The study was designed to provide a measure of how well the unit performed with different amounts of sleep per day. Three principal questions were developed to be addressed by the study: (1) what levels of minimal sleep maximized unit performance, (2) how much sleep was required to maintain minimal levels of performance, and finally, (3) how do individual differences in sleep requirements affect unit performance and unit sleep discipline.

DISCUSSION

The AURA Model

The Army Unit Resiliency Analysis (AURA) model was developed to represent mission effectiveness. The model considers the combination of the assets available to a unit and the individual jobs which must be done correctly in a time sequence to appropriately complete a mission segment. The assets of a unit are selected based on the table of organization and equipment and the jobs that are developed are based upon the ARTEP standards for jobs to be performed and the performance measure to be gained from the proper execution of the job. In the case of this study, the M109 Artillery Unit was selected, a unit previously reviewed and found to be appropriate for AURA studies by the U.S. Army Artillery School. The unit represents the various people and their location on the battlefield and the specific jobs they must accomplish. After doing some preliminary studies, the major focus of this sleep study was on the people assigned as the gun

section chief, gunners, and loaders within this unit because they were found to be the personnel that were the most severely taxed by the selected mission, continuous firing.

The Sleep Methodology

The sleep methodology that was used within AURA was modified based upon the characteristics previously identified as appropriate by Dr. Terry Klopccic. Basically, there are six key variables to identify the sleep cycle within AURA. These variables include the definition of the unit of effective sleep, the maximum allowable accumulation of these effective sleep units, the level of sleep units which are equivalent to 100% effective performance, and the use rate of effective sleep units during work activities. The final variable used in the methodology was the size of the reservoir of effective sleep units that can be saved for use at a later time.

Sleep Accumulation Function

The basic sleep accumulation function is constructed in four segments (see Figure 1). For the first 10 minutes, no "minutes of effective sleep" are generated; for minutes 10 through 30, the person is given half-credit for the amount of time asleep (i.e., 10 minutes). So a person at 30 minutes into their sleep period will have accumulated 10 "minutes of effective sleep." From 30 minutes until the point where they have made up 80% of the difference between where they started at the beginning of the sleep period and maximum extent of their reservoir, a person is

able to accumulate effective sleep on a one-to-one basis one minute of effective sleep for each minute asleep. After replenishing 80% of the deficit, a person only accumulates half of a minute of effective sleep for every minute the person sleeps. Finally, once a person sleeps sufficiently long to reach the maximum of their reservoir, further sleep accrues no further benefit to the sleep accumulation function. If a person is in balance in working 18 hours and is sleeping 6 hours, during that 6-hour sleep period he would accumulate 283 1/3 effective minutes of sleep and be at maximum sleep accumulation at the end of the sleep period. If a person was very tired, having worked more than 18 hours, then a 6-hour sleep period could potentially yield

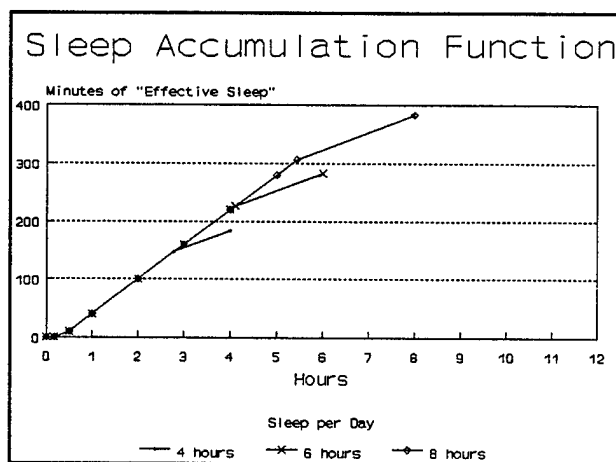


Figure 1. Sleep Accumulation Function

340 "minutes of effective sleep" in a 6-hour period because the reservoir remained below the 80% threshold of diminishing returns.

Work Degradation Function

The rate at which sleep is used, is based on observations of degradations in performance in individuals deprived of sleep for extended periods. The Department of Behavioral Biology of the Walter Reed Army Institute of Research has observed that the maximum time that a person can work without effective rest is 4 days. Measures of a variety of mental (cognitive) tasks indicate that the rate of correct performance declines an average of 25% per day.

It has also been observed that a person in their normal sleep cycle, where they are in balance, will be able to retain 100% performance in their job for 18 hours during the first day of work in that environment. A person that has a nominal sleep requirement of 6 hours of sleep to 18 hours of work will still be performing at 100% of their capability at the end of the 18 hour work period. For times after that, if work is to continue, we modeled a linear drop in the effectiveness at which they were able to perform their job. Jobs differ in their demand on sleep curves. An Army Research Institute study of sleep requirements in an artillery unit indicated that the executive officer, gun section chief, gunners, and the rest of the crew members had distinct rates at which their performance dropped when deprived of sleep. With these data, we extrapolated the rate at which effectiveness dropped during a 12-hour mission profile to estimate the rate of effectiveness drop for continuous and sustained operations during a 24-hour scenario (see Figure 2).

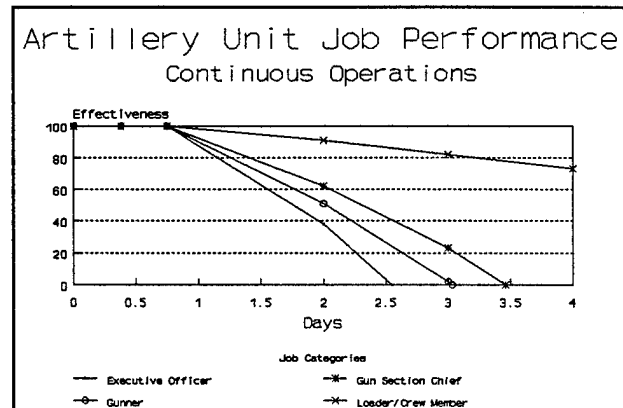


Figure 2. Work Degradation Function

Using these empirical data, different calculations were made to establish values for each of the key parameters used within the AURA model. For Phase I and II of this effort, without individual variation, a person was assumed to be in balance if he slept for 6 hours and worked for 18 hours. That meant that the amount of effective sleep that he would use in 18 hours would be exactly 283.3 "minutes of effective sleep" per 18 hours, the amount that can be earned in 6 hours of sleep. By fitting the

change in effectiveness observed from the WRAIR/ARI data set, it was possible to find how many "minutes of effective sleep" would be used per minute of work. It was also possible to equate the percent effectiveness with the "minutes of effective sleep" in terms of use per minute of work. The size of the reservoir of sleep available for the four classes (executive officer, gun section chief, gunner and crew member) was determined. Also determined was the point of 100% effectiveness in job performance. In order for performance to remain at 100% for the first 18 hours of work, the reservoir contained a "reserve" capacity above the 100% effectiveness threshold equal to the amount of sleep required to perform 18 hours of work (i.e., 283 1/3 "minutes of effective sleep"). After that point, continued work without sleep degrades effectiveness in a job specific manner (Figure 2).

In Phases I and II of the study, all individuals were assumed to have identical sleep requirements to remain 100% effective; each individual was given the capability to perform the average job at 100% effectiveness for 18 hours per day with 6 hours of sleep, provided there was no carry-over sleep deficit from prior days.

Sleep Requirements Distribution

For Phase III of the study, the differences in sleep balance points for individuals were assigned according to an approximate normal distribution of requirements. The distribution of sleep requirements was categorized into four classes (see Figure 3).

- o 10% of the people were assumed to require 7 1/2 hours of sleep,
- o 40% of the people would require 6 1/2 hours of sleep,
- o another 40% of the population would require 5 1/2 hours of sleep, and
- o 10% of the population required 4 1/2 hours of sleep

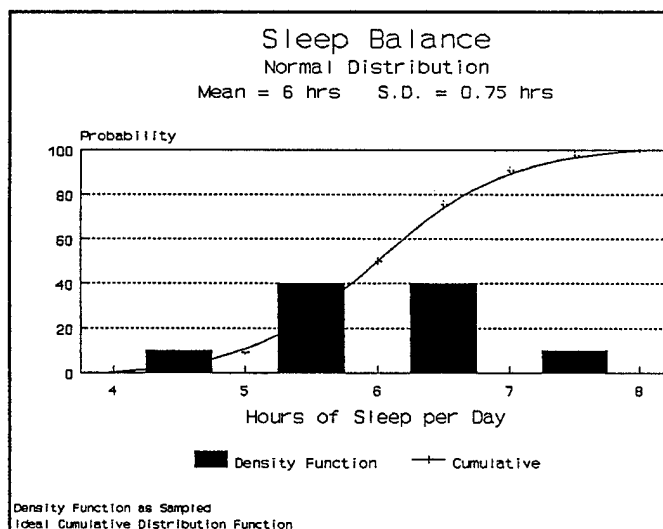


Figure 3. Sleep Requirements Distribution

which resulted in an approximation to the normal distribution with a mean of 6 hours. The differences in sleep balance point required an adjustment to the size of the reservoir for individuals doing different jobs. The absolute rate at which "minutes of effective sleep" were used was individualized to reflect both the rate of use imposed by the job and, the adjusted size of the reservoir for the individual.

The Unit

A M109 Artillery Unit using self-propelled 155mm artillery was used as a standardized unit. This unit was selected because there were data on individual degradation and independent model predictions of individual as well as unit performance levels. The unit was further amenable to this type of study because the mission of firing rounds was a mission which could be quantified and could show the deterioration that was expected after suboptimal sleep.

With this particular unit, the AURA model considers ways to perform the continuous firing mission:

- o The unit is 100% effective when it has available a gun section chief, gunner and loader all contributing to job accomplishment with 100% individual effectiveness.
- o The unit is 70% effective when it has a gun section chief and gunner performing the mission at 100% individual effectiveness.
- o The unit is 50% effective when it has a gun section chief and loader performing at 100% individual effectiveness.
- o The unit is 30% effective when it has a loader and driver performing the continuous firing mission at 100% individual effectiveness.

The exact profile and the exact period of sleep could become desynchronized across the various gun crews and the various ways that the job could be performed in Phase II of the study. This did in fact happen and results showed that the amount of time that the individuals sleep from day to day could vary widely. In certain instances, certain combinations of the ways to do the job actually come into play.

The AURA input file for the M109 artillery unit is provided in Appendix A.

The Experiment

In Phase I, unit effectiveness was assessed on an hourly basis for up to 20 days. The input set for AURA was configured to simulate 1 day at a time and to pass the ending status of any particular day to the starting conditions for the next day of the simulation. The sleep parameter for going to sleep was calculated to insure that at least one sleep period (of the minimum duration being simulated) would be accomplished if the person worked continuously during the day being simulated. In other words, if the simulation called for a minimum sleep period of 6 hours per day, the criterion for placing individuals to sleep was set to a value that would initiate a 6-hour sleep period after 18 hours of work. While this created an artificial work/rest pattern that no real Army unit would be expected to follow, it did greatly simplify the simulation and generated correct measurements for the daily activities of this unit (since each gun crew operates independent of the other gun crews within the AURA representation for this unit). Minimum sleep periods tested during this phase were 1, 4, 6, and 7 hours (see Figure 1). At least one sleep period was scheduled every day. The balance between work and sleep requirements was set so that the average job demand would be satisfied by 6 hours of sleep every day. The fatigue rates were derived from mathematical fits from available WRAIR/ARI data as shown in Figure 2 (Personal communications with Dr. Gregory L. Belenky of WRAIR and ARI Research Product 80-4b). The obtained levels of unit effectiveness under the four sleep regimens were the primary outcome measures.

Phase II of the experiment was conducted to evaluate the effect of setting minimum levels of individual performance. Again, unit effectiveness was determined every hour and the sleep accumulation function, the balance point between work and sleep, and the rate of change in effectiveness during work was identical with the Phase I values (see Figures 1 and 2). The resulting sleep parameters were again passed from the end of 1 day to the beginning of the next day. In Phase II, the criteria for forcing an individual to sleep was based on individual effectiveness rather than an imposed sleep regimen as in Phase I. The minimum level of the sleep reservoir was assigned to insure that the individual effectiveness of the personnel did not drop below a specific level. The levels used were 100%, 88%, 75%, and 50%. The obtained sleep per day required to maintain these levels was the primary outcome measure.

For Phase III of the study, 20 days of performance were studied under 4, 5, 6, 7, and 8-hour sleep per day regimens. Again, unit effectiveness was determined every hour and the sleep accumulation function and the rate of change in effectiveness during work was identical with the Phase I values (see Figures 1 and 2). The daily sleep requirement for individuals (i.e., balance point between work and sleep) was randomly assigned to

specific jobs, using the distribution identified in Figure 3. Five such assignments (trials) were studied to obtain a representative sample of the effects of individual differences on expected unit effectiveness and the efficiency of different sleep regimens for maintaining unit performance.

FINDINGS

Phase I

The minimum sleep period of 7 hours per day shown in Figure 4 was more than sufficient to maintain 100% unit effectiveness, given the individual requirement of 6 hours per day.

With 6 hours of sleep as the minimum sleep period, every person in the unit is allowed to sleep an amount of time equal to the average daily loss of effectiveness; however, the loss of effectiveness for the Gun Section Chief and for the Gunner exceed the average rate of degradation putting these individuals into sleep deficit. Degradation in unit effectiveness, shown in Figures 5 and 6, mirrors this individual fatigue.

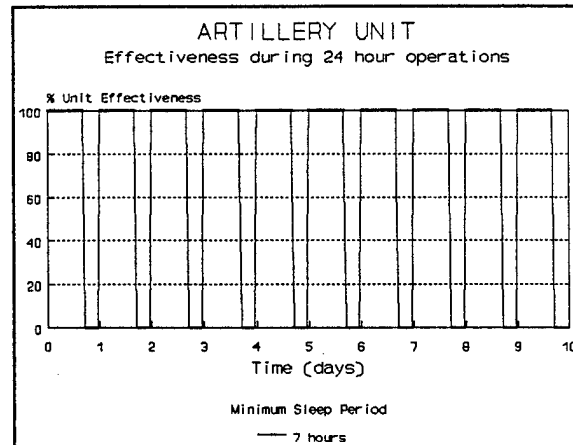


Figure 4. Effectiveness with 7-Hour Minimum Sleep Period

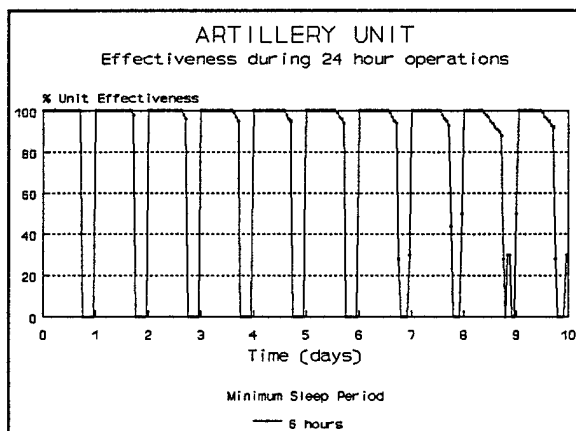


Figure 5. Effectiveness of 6-Hour Minimum Sleep Period (Days 1-10)

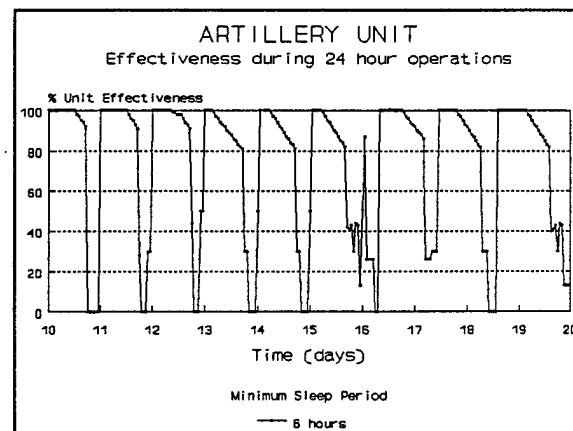


Figure 6. Effectiveness of 6-Hour Minimum Sleep Period (Days 11-20)

Starting as early as the ninth day of the 6-hour simulation the model begins optimizing the performance of the unit by using different firing teams to accomplish the mission.

Four hours minimum sleep per day is insufficient to maintain performance of key personnel as demonstrated in Figure 7. This general decrease in the level of performance forces the unit to adopt strategies that use combinations of the two man firing teams, (i.e., Gun Section Chief and Gunner, Gun Section Chief and Loader, and finally Loader and Driver) to accomplish the firing mission. In addition, multiple sleep periods per day become the rule after the seventh day of continuous operations. Note that even though multiple sleep periods would result in at least 8-hours of sleep per day, high levels of unit effectiveness were not restored.

The 1 hour of minimum sleep period results in a precipitous drop in unit effectiveness on the second day of firing as seen in Figure 8. On the following days, the unit maintains a steady level of capability by sleeping multiple times a day and resorting to various two man firing teams to gain additional sleep time for the personnel in the unit. Even though the 1-hour sleep period resulted in the gain of only 40 minutes of "effective sleep", the model optimized performance by increasing the frequency of these "naps" rather than increasing the sleep period. (For instance, 4 hours of sleep generates 210 "minutes of effective sleep" where four 1-hour sleep periods only generates 160 "minutes of effective sleep").

In summary, a minimum of 7 hours of sleep per day maintains maximal effectiveness levels indefinitely. A minimum of 6 hours of sleep per day maintains acceptably high levels of effectiveness for several weeks. A minimum of 4 hours of sleep per day

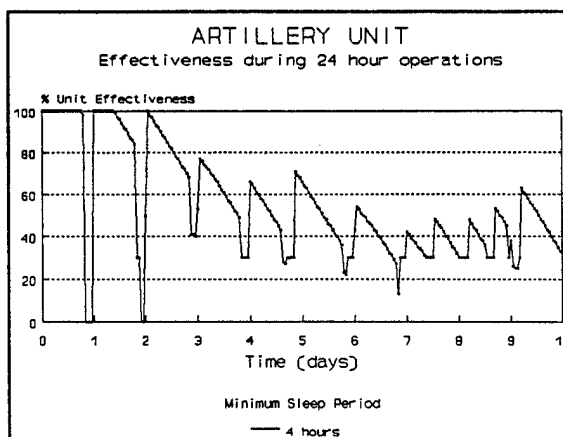


Figure 7. Effectiveness of 4-Hour Minimum Sleep Period (Days 1-10)

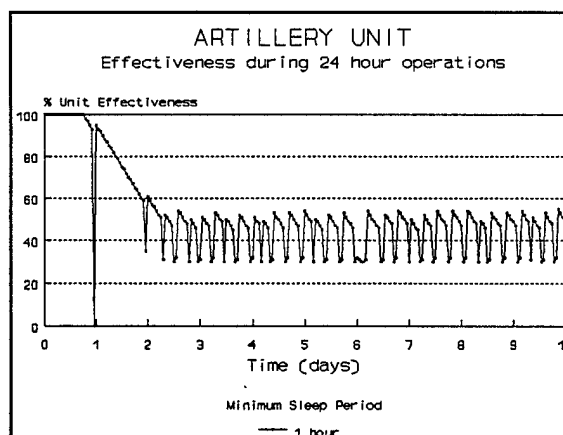


Figure 8. Effectiveness of 1-Hour Minimum Sleep Periods (Days 1-10)

maintains acceptable levels of effectiveness for 2 to 3 days while 1 hour of sleep per day maintains performance for less than 2 days.

Productivity was assessed as the average number of rounds per tube that could be fired on target during a 24 hour period by the unit. This measure of effectiveness was chosen to present the time smoothed performance measure that allowed comparison between different sleep disciplines. The choice of this measure of effectiveness was made because it was an important measure of the objective performance of the firing team conducting the assigned mission. Productivity results are presented in Figures 9 and 10.

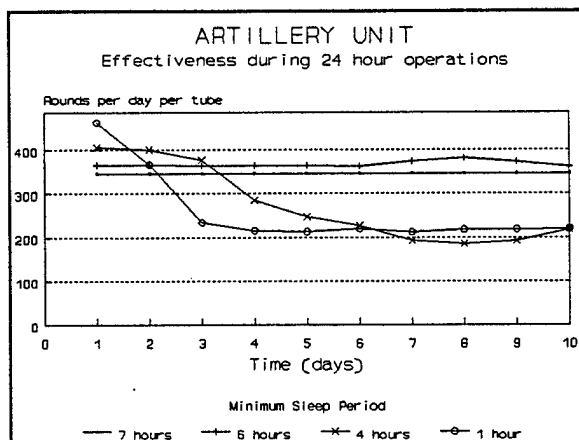


Figure 9. Productivity of Different Minimum Sleep Periods (Days 1-10)

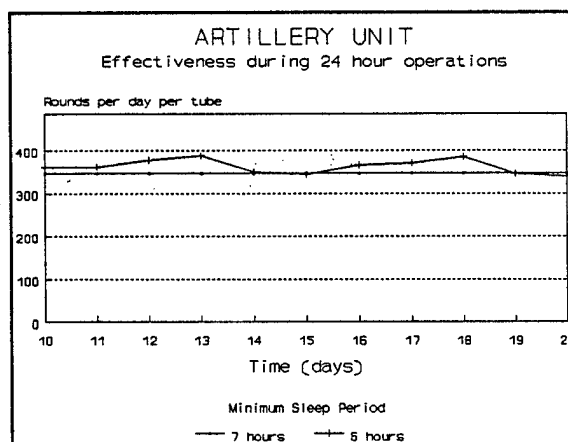


Figure 10. Productivity of Different Minimum Sleep Periods (Days 11-20)

In Phase I, with no individual differences in sleep requirements, a minimum of 7 hours of sleep maintains stable productivity in terms of rounds per day per tube indefinitely. A minimum of 6 hours of sleep generates slightly higher levels of productivity for at least two weeks. A minimum of 4 hours of sleep generates highest productivity in terms of rounds per day per tube for the first 2 to 3 days of performance.

Phase II

In Phase II, minimum levels individual effectiveness were demanded and used to determine the point at which an individual was sent into a sleep period. Results are presented in Figures 11 through 14.

For this Phase, a minimum sleep period of 3 hours was chosen, but multiple sleep periods per day were permitted. The effectiveness for the four levels of demanded individual effectiveness reflected AURA strategies which relied primarily on two man gun crews and a work/rest cycle which was shorter than the 24-hour day to optimally maintain unit effectiveness.

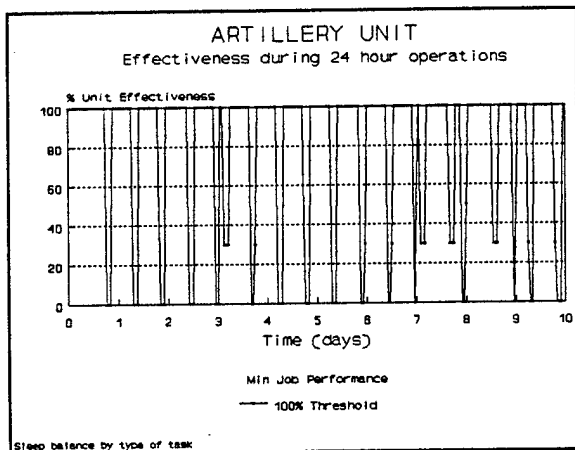


Figure 11. Unit Effectiveness with a Minimum of 100% Individual Effectiveness

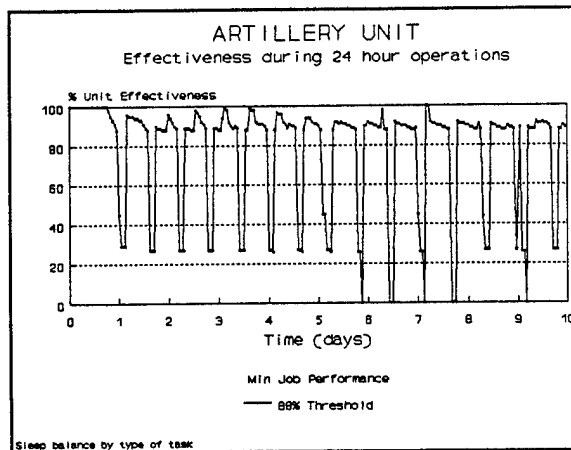


Figure 12. Unit Effectiveness with a Minimum of 88% Individual Effectiveness

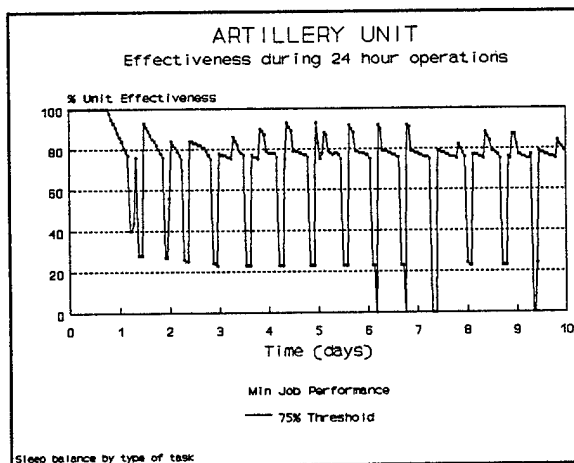


Figure 13. Unit Effectiveness with a Minimum 75% Individual Effectiveness

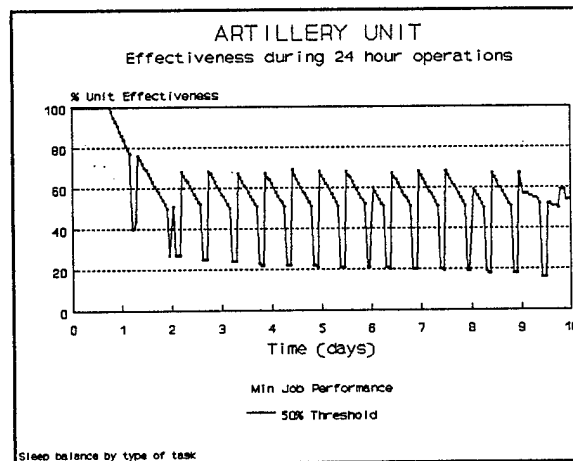


Figure 14. Unit Effectiveness with a Minimum of 50% Individual Effectiveness

The amount of sleep per day required for the Gun Section Chiefs to maintain the demanded levels of individual performance varied on a daily basis with an average of 5.49 hours per day (Figure 15). To maintain 100% effectiveness, minimal variations from that average value were found. As the individual effectiveness threshold was reduced to lower levels, the day to day variation in the sleep time reflected the strategy of shortening the time between sleep periods and most of the variation between days reflects when the sleep periods were taken. The daily sleep requirement for all thresholds averaged the same amount of sleep after 1 or 2 days in the missions; lowering the performance threshold for sleep did not save sleep time in the long run.

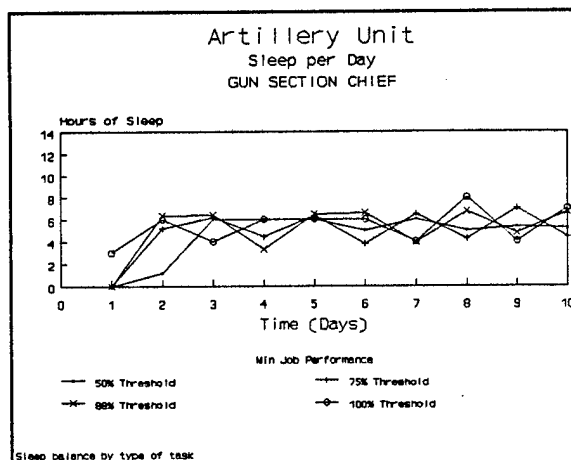


Figure 15. Sleep for the Gun Section Chief

The amount of sleep per day required of the gunner to maintain optimal performance averaged 7.22 hours per day (Figure 16). The variation in the amount of sleep necessary for any particular strategy for limiting individual effectiveness caused even wider variation in the hours of sleep that were taken on any particular day in the scenario. The Gunner's sleep per day was also affected by the optimization scheme that was adopted within AURA. On the second day for the 50% threshold case and the seventh day for the 75% threshold case the optimization routines of the model detected an advantage to give the Gunners "extra sleep" to return them to 100% individual effectiveness. The model then insured that the gunners were given extra sleep to maintain that level of individual effectiveness on succeeding days of the scenario and the set minimum level of effectiveness was not used to place the Gunner personnel to sleep, rather the model kept these personnel at top effectiveness potential.

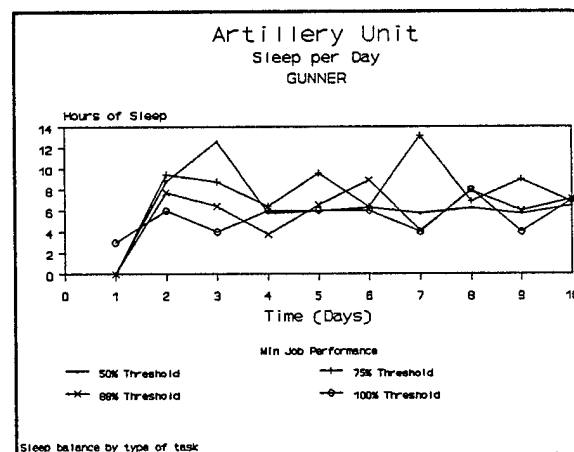


Figure 16. Sleep for the Gunner

The Loader sleep profile is different in several ways from the Gun Section Chief and the Gunner sleep profiles (Figure 17). Because the Loader tasking has low cognitive demands, the rate that effectiveness drops as the job is performed is much lower than the rate of the other two team members of the firing team and lower than the amount of "effective sleep" generated during 6 hours of sleep per day. The net effect of these two factors was that the Loader could work for a considerable period of time before the individual effectiveness thresholds were reached (9 days for the 50% level of individual effectiveness). Nevertheless, once performance deteriorated to that level, an average of 5.31 hours of sleep were required to maintain adequate performance with the variation from day to day being seen on the lower hours of sleep side of the 6-hour point.

Unit effectiveness parallels the set levels of individual performance. Six to 9 hours of sleep were required to maintain performance independent of the targeted level of individual performance. Unit productivity was highest when individual performance was maintained at 100% effectiveness (Figure 18).

Phase III

The implementation of individual variation in the sleep requirement equilibrium did not change the characteristics of the relationship between work and sleep. The gun crew adopted the sleep and work pattern dictated by the minimum sleep period being established in a particular series of the simulation. Randomly

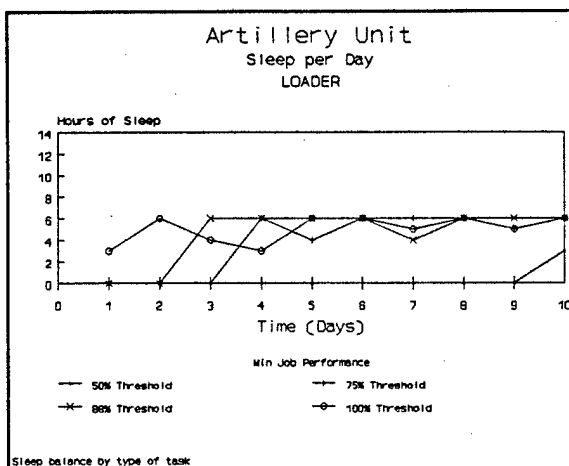


Figure 17. Sleep for the Loader

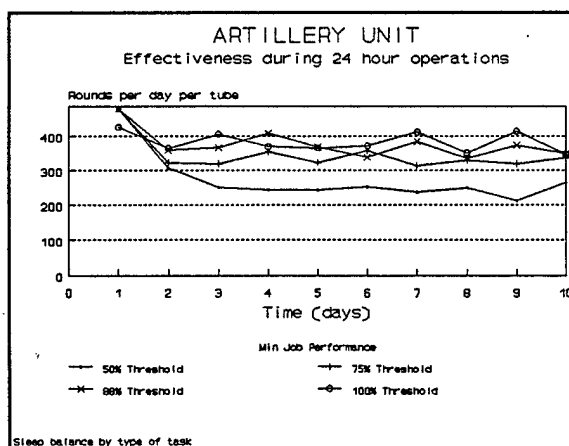


Figure 18. Productivity of Different Minimum Individual Performance Levels (Days 1-10)

assigning sleep requirements to specific jobs did change the individual performance levels of the various crew members. The effectiveness of each crew reflected the limitations of the most ineffective individual on the team. The potentially most serious situation occurred when the minimum sleep per day was set to 4 hours per day. This allowed 20 hours of work each day and rapidly pushed every member of the team into sleep deficit.

The format for the plots for each sleep regimen reflects the stochastic distribution of individual variation in sleep requirements. For these charts, a double wide line is used to depict the average value while dots are used to represent the data obtained from each trial. It has been determined that three to five trials are necessary to develop average values representative of the population of possible distributions of individual variation of sleep requirements.

The severe demands of the 4-hour sleep regimen were accommodated within AURA by two adaptations. First, firing missions were conducted by two combinations of assets that alternated between work and sleep; the Gun Section Chief and Gunner acted as one firing team and the Loader and Driver acted as the other. Second, after the third or fourth day of operations all personnel were given two 4-hour sleep periods each day. Despite these adaptations, Figures 19 and 20 show that unit effectiveness was generally below 50% after 4 days of operations.

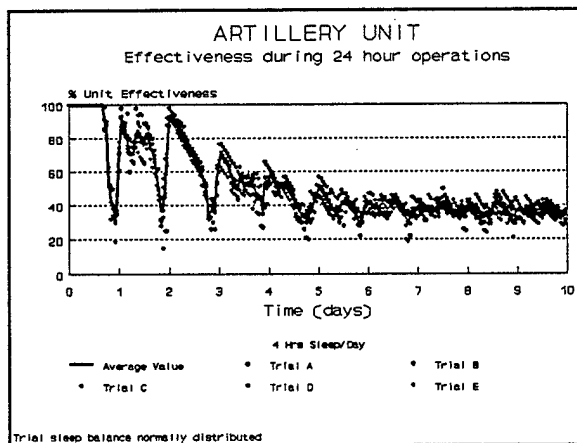


Figure 19. Four Hours Minimum Sleep per Day (Days 1-10)

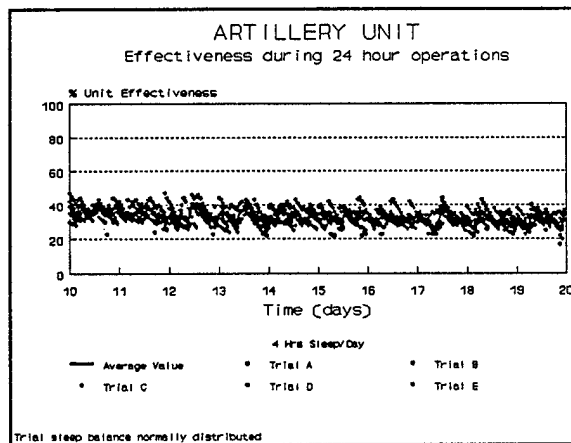


Figure 20. Four Hours Minimum Sleep per Day (Days 11-20)

The 5-hour sleep regimen was less severe than the 4-hour sleep regimen as shown in Figures 21 and 22. Only 10% of the personnel on average were able to sustain operations without performance deficit with 5 hours of sleep. As a consequence, the

performance of each of the gun crews was severely affected and in fact, after 4 to 5 days all of the gun crews began taking two 5-hour sleep periods each day.

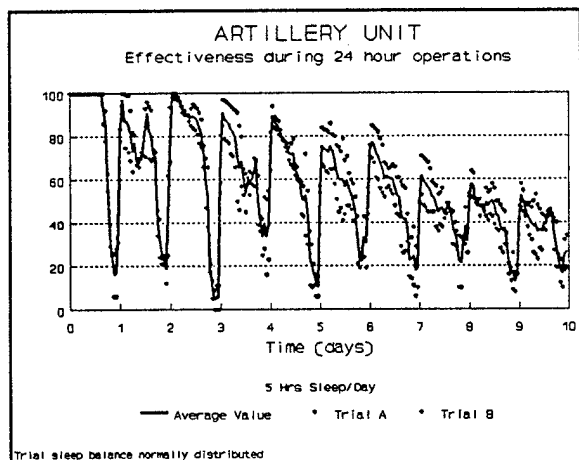


Figure 21. Five Hours Minimum Sleep per Day (Days 1-10)

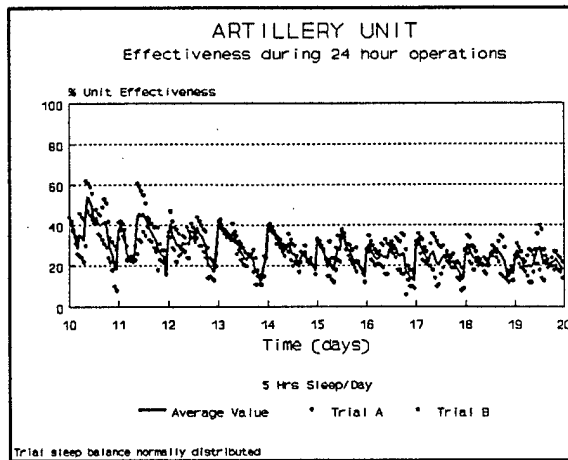


Figure 22. Five Hours Minimum Sleep per Day (Days 11-20)

The AURA model opted to operate with Gun Section Chief, Gunner, and Loader as the principal gun crew during the 5-hour runs for the first 8 days of the scenario while maintaining one sleep period per day. A transition occurred as the deficit incurred by the sleep deprivation became more serious and the unit adopted a strategy which used the Gun Section Chief and Gunner alternating with the Loader and Driver with each group sleeping for two 5-hour periods each day.

The 6-hour minimum sleep period provided sufficient sleep time to meet the requirements for sustaining operations of 50% of the assigned personnel (see Figures 23 and 24). Only 10% of the personnel would end up seriously sleep deprived during the conditions of 6 hours minimum sleep per day. As a consequence, several of the gun crews could potentially be sustained indefinitely on this regimen.

The predominant characteristic of the 6-hour minimum sleep period is that the entire 20-day period was accomplished using the Gun Section Chief, Gunner, and Loader to accomplish the mission and there was no unit-wide transition to alternating between two man firing teams. It appears that gun crews that were in serious deficit were able to modify their actions to either two man firing teams or to get two 6-hour sleep periods and return to a normal cycle of three man firing teams and one sleep period a day. Thus, 6 hours of sleep is successful for

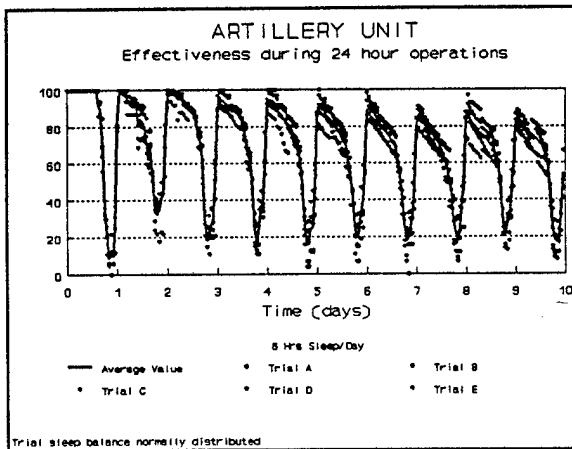


Figure 23. Six Hours Minimum Sleep per Day (Days 1-10)

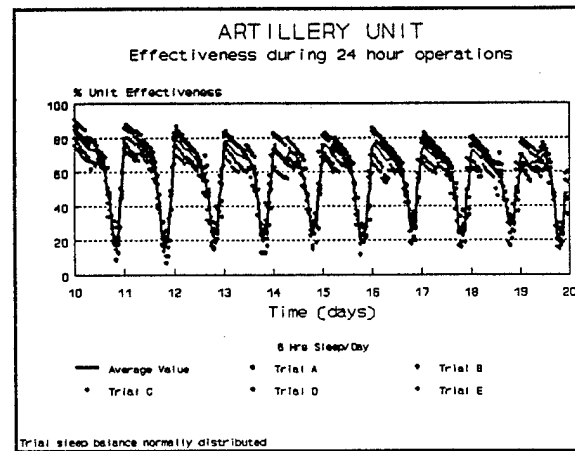


Figure 24. Six Hours Minimum Sleep per Day (Days 11-20)

long term high levels of performance; however 40% of the unit requires 6.5 hours of sleep and is only getting 6 hours of sleep and the performance is steadily decreasing as a consequence. At the end of the 20-day operation, unit effectiveness is consistently less than 80%.

The 7-hour minimum sleep period represented in Figures 25 and 26 is sufficient to meet the full sleep requirements of 90% of the assigned personnel and the 10% of the personnel in deficit

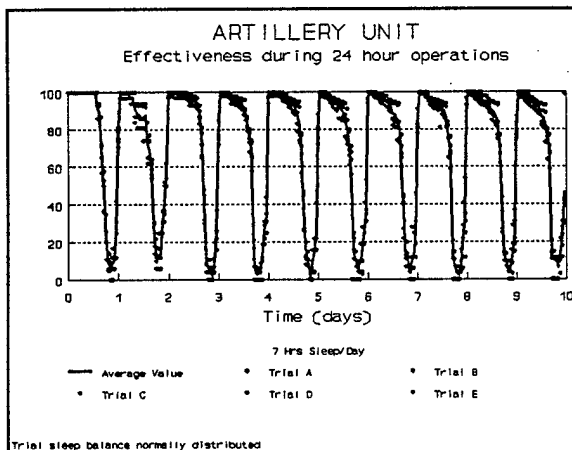


Figure 25. Seven Hours Minimum Sleep per Day (Days 1-10)

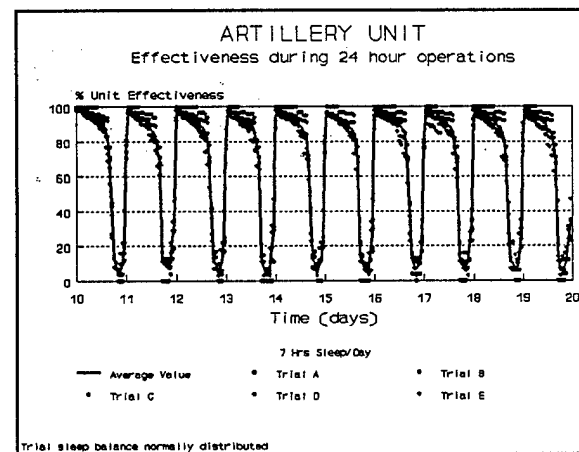


Figure 26. Seven Hours Minimum Sleep per Day (Days 11-20)

are missing one half-hour of sleep per day on average. Most of the gun crews could be sustained indefinitely on this regimen and maintain the high levels of effectiveness characteristic of maintaining the three man firing team of Gun Section Chief, Gunner, and Loader.

The effectiveness of the unit with 7 hours of sleep per day remains stable. A minor periodic change in effectiveness is a consequence of the unit adopting a strategy of minor use of the two man firing team to restore 100% effectiveness to team members with a 7.5-hour sleep requirement. At the end of the 20-day operation, unit effectiveness remains consistently above 80%.

The 8-hour sleep regimen provides sufficient sleep to insure that each gun crew can maintain 100% throughout the 16-hour firing day with the three man firing team of Gun Section Chief, Gunner, and Loader (see Figures 27 and 28).

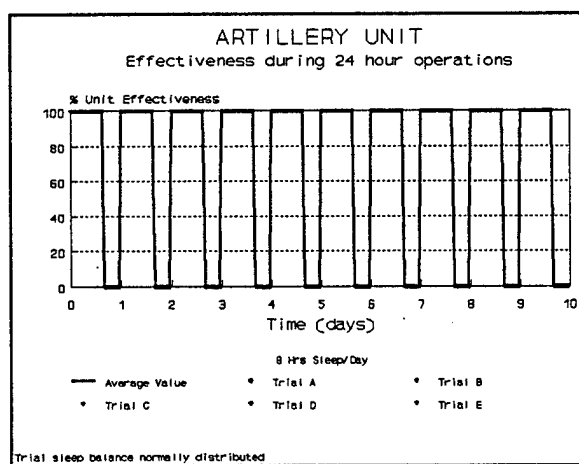


Figure 27. Eight Hours Minimum Sleep per Day (Days 1-10)

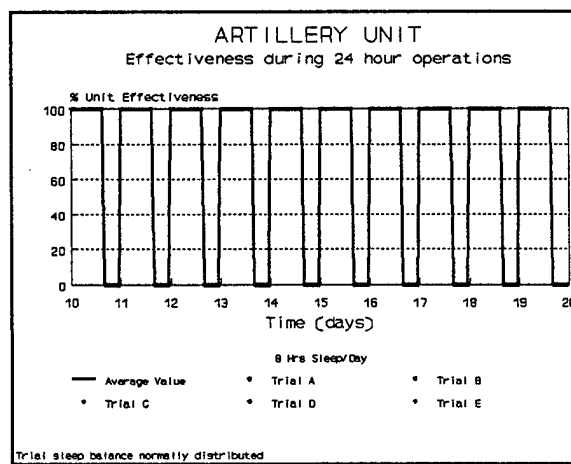


Figure 28. Eight Hours Minimum Sleep per Day (Days 11-20)

The 8-hour scenario provides absolutely stable performance and optimum performance during the waking hours of the gun crew. Every individual can work the entire duration of the work period without a drop in individual performance. This maximal performance during waking hours is purchased at the expense of one additional hour of sleep (0% effectiveness) compared to the 7-hour regimen.

In summary, the 6-hour sleep regimen is most sensitive to the introduction of variation in individual sleep requirements. Variation between trials is small compared to the decrement introduced by individual variance. Maximum effectiveness is no

longer maintained with 7 hours of sleep per day. Maximum effectiveness can be maintained with 8 hours of sleep per day indefinitely.

Unit Productivity

Eight hours of sleep per day maximizes individual performance but is slightly less productive overall than seven hours of sleep because of the loss of one additional hour of work per day (see Figure 29). The combined effects of days into the mission and sleep regimen (hours per day) on unit productivity are illustrated in the response surface of Figure 30. Note that optimal productivity is maintained by a 7-hour minimum sleep period each day and that minimal productivity is generated by a 5-hour minimum sleep period each day.

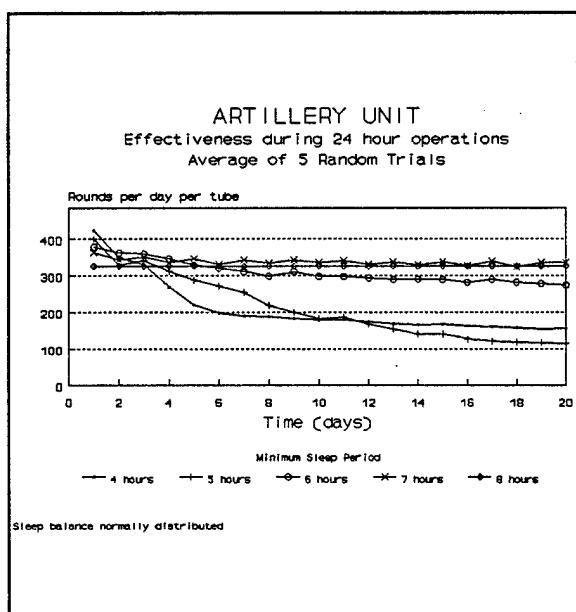


Figure 29. Productivity with Different Minimum Daily Sleep

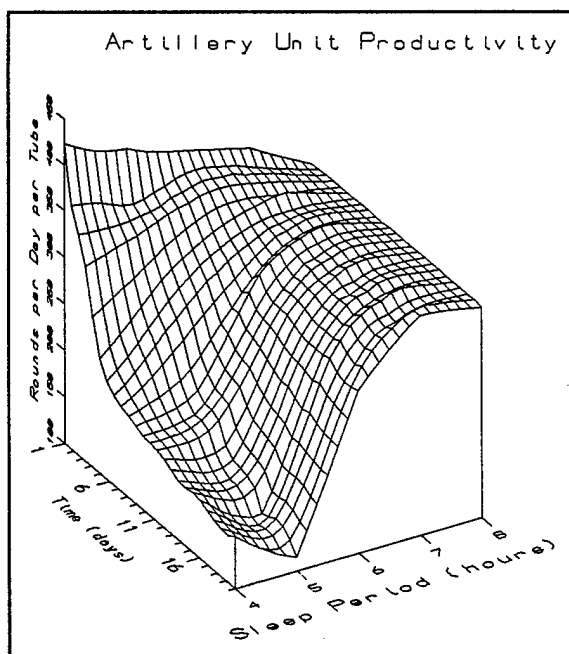


Figure 30. Productivity Response Surface

Four hours of sleep generates highest productivity only on the first day and results in rapid loss of the capacity to sustain operations. Seven hours of sleep generates higher productivity than 6 hours of sleep after the first 3-5 days. Eight hours of sleep also generates high sustained productivity but is generally less effective than 7 hours of sleep because of the loss of one additional hour of work time per day.

The 4-hour sleep period lowered the effectiveness of the individuals to such a low point that 4 hours of sleep was not sufficient to maintain them after the first several days. Most of these people were going to sleep twice during a 24-hour period because their effectiveness had dropped down to 0% as they used all of the "minutes of effective sleep" they were able to generate. For the 5, 6, and sometimes 7-hour cases, multiple sleep periods during the 24-hour period of simulation were possible, did occur, but were not a predominant factor in the overall unit performance. The 4-hour runs reached a minimum baseline which was driven by the multiple sleep periods per day. In fact, in the 4-hour runs, the model tended to put personnel to sleep for more than one period at a time when their effectiveness dropped to 0%. The consequences of this can be seen by comparing runs generated which allowed multiple back-to-back sleep periods with runs generated which forced a single sleep period to be accomplished before returning to work. Both cases resulted in multiple sleep periods in a 24-hour period, but the ability to generate 8 or more hours of continuous sleep was effective in maintaining a minimum level of individual performance. With less than 8 or more hours of continuous sleep, the individual performance level would drop to 0% which would initiate another sleep period for the individual before performance could continue.

LIMITATIONS

This modeling effort provides a solid first step in systematically using available data to understand the implications of sleep disciplines in a general way using the chosen unit. The use of the results of this effort represent events and relationships that are likely to exist in a wide variety of units and tactical situations. Several fundamental issues in sleep modeling which represent potential limitations are discussed in the following paragraphs.

It is important to understand that the scientific data drives the modeling effort. The basis for the model and for comparing the model to otherwise identified sources is that it must accurately represent the data when the data are available. It is important to understand that some very important data for testing the validity of the model are still lacking.

The representation of the sleep accumulation function and the sleep utilization functions (supply vs demand) appear to be reasonably robust. The principal weakness is that the audit trail for this data must be documented and the demand profile of the ARI data must be understood. By assuming that the data in the ARI document represents 12 hours of mission support per day and using the documented medium workload case, the AURA results differed from the published levels of unit effectiveness by 1% for the 1- and 3-day results and 2% for the 5-day results (ARI Research Product 80-4b).

The mission profile represented in the unit database is the second potential problem. The mission represented for this unit is a continuous firing mission. While the mission represents the receipt of the firing mission, aiming, loading, firing, and reporting/communications tasks, it does not represent any movement tasks nor does it involve the alignment and positioning of the tubes. Because of the limited representation of the required activities of the unit, many of the personnel are not involved in any activities. This restricted representation of the activities of the unit is not a complete and accurate depiction of the required personnel demands for sleep. Use of the current model and database as tools for assessing the impact of sleep requirements on either continuous or sustained operations is an appropriate use of the model, but a detailed operations analysis effort is required to identify a robust representation of all of the missions which contribute to effective unit performance.

In the high threat counter-battery environment which dominates most contingencies, the unit will be conducting its firing mission and moving to a new location as soon as the last round is out of the tube. Also, it is highly likely that the battery will separately conduct the firing mission from each of the platoons. The first platoon would typically begin the firing mission. When the counter-battery fire is returned, the firing platoon would move while the second platoon would provide supporting firepower. A secondary complication is that it is probably not going to be possible for anyone in the unit to get sleep during the period of a move.

It is not reasonable to represent the unit-wide sleep balance for this unit using a continuous firing mission as the only demand for unit assets (for purposes of force structuring). In this case, 24 of the 75 personnel in the unit are being worked to their limits while the remaining personnel are for the most part, in a limbo state with no demands. In the real world, the unit would be doing other things which would place demands on all the unit's assets, assets that were not necessary for accomplishing another task at a particular time would probably participate in other tasks--like a 30-day continuous firing mission. A scenario which scripts the activity of the unit over a suitable time period would be an important contribution to understanding what was happening to the demand for work and the resulting unit effectiveness. Considering this limitation, it would not be appropriate to use these results as a predictor of actual levels of effectiveness of an artillery unit. Rather, it is a tool for comparing the relative value of various sleep disciplines for maintenance unit effectiveness. The essential characteristics of this artillery unit performing this hypothetical operation are that it has 1) limited personnel assets with limited cross-training and 2) key personnel critical for optimal performance.

To the extent that these two factors are generally true for all combat units, the relative evaluations of sleep discipline are generally applicable.

CONCLUSIONS

The sleep methodology used in conjunction with the AURA methodology enables hypothesis development and evaluations that would be extremely difficult and potentially dangerous to be conducted with Army units in the field. While current knowledge has been used to develop the methodology and the results seem reasonable, there are many questions that remain to be answered and key pieces of the puzzle that must be fit into place.

Individual differences are important in looking at the consequences of sleep discipline since they lead to key failure modes of teams involved in unit operations. Use of individual differences in sleep requirements in Phase III revealed sensitivities and potential problems that may be difficult to identify and explain using expected value sleep requirements.

Seven and 8 hours of sleep provide sustained performance levels for long term operations. Six hours of sleep provides high performance for long periods, but is subject to degradation in the level of performance that increases over time. Five hours of sleep provides the sleep required for operation during a few days and minimal performance levels thereafter. Four hours of sleep provides high levels of performance for a short burst of activity. However after a few days, the 4-hour sleep regimen provides only a residual capability to perform the mission.

It has been found that sustained effective performance requires the same amount of sleep on average, regardless of the chosen level of performance (Phase II). In other words, to achieve 100% effectiveness requires no more sleep on average than to achieve 50% effectiveness. In addition, the change of unit effectiveness level and the sustained performance at less than 100% effectiveness is accompanied by large swings in the amount of sleep time that is used, but the average hours of sleep remain at the level which would have sustained operations at 100% effectiveness.

RECOMMENDATIONS

The current sleep methodology is based upon data which reflects performance levels during total sleep deprivation or performance levels when sleep requirements match daily sleep levels. Experiments which assess the performance level achievable with intermediate levels of sleep on a daily basis would allow an important test of the predictions of the methodology to insure that the underlying hypothesis of a sleep reservoir model for sleep is valid. For example, the reservoir model predicts

that suboptimal levels of sleep per day lead to progressive cumulative deficits in performance. Other sleep models might predict equilibrium suboptimal performance.

Data on the distribution of individual sleep requirements and the fatigue parameters associated with a broad spectrum of Army jobs supporting different units and missions would allow the investigation of the consequences of sleep discipline to be generalized. More attention needs to be given to the degradation rate of jobs that involve a combination of cognitive and physical demands or involve primarily physical demands. In addition, the accumulation of this data would facilitate sleep discipline strategies tailored to special requirements.

Finally, The investigation of fatigue interactions with environmental and occupational stressors (thermal, vigilance, disease) should be reviewed for development into a more complete description of individual performance in combat and mission effectiveness models.

The effects of fatigue on combat operations should be investigated by transferring the sleep methodology to combat force-on-force simulations.

REFERENCES

Effects of Continuous Operations (CONOPS) on Soldier and Unit Performance: Review of the Literature and Strategies for Sustaining the Soldier in CONOPS. WRAIR Technical Report No. BB-87-1 (April 1987).

Human performance in continuous operations: Volume II, Management guide. ARI Research Product 80-4b (December 1979).

Personal communication with Dr. Gregory L. Belenky in March 1989 concerning degradation in performance with sleep deprivation.

APPENDIX A

AURA Unit Input File for
M109 Artillery Unit

REPertoire
WEAPONS
CHM12MG, TOXIC
FGS
SP FA AUTO MECH, PERSONNEL, MECH, CREW
FA WEAPONS MECH, PERSONNEL, MECH, CREW
SP FA SYSTEM MECH, PERSONNEL, MECH, CREW
SVC TM CHIEF, PERSONNEL, MECH, CREW
AUTHORITY, PERSONNEL
PLT LDR, PERSONNEL
FA FD CREW MANUAL, PERSONNEL
FDO MANUAL, PERSONNEL
FA FD CREW COMPTR, PERSONNEL
FDO CALCULATOR, PERSONNEL
PLT DRIVERS, PLT CREW, PERSONNEL
PLT SGT, PLT CREW, PERSONNEL
M577 DRIVER, PERSONNEL
FA FD CREW, FDC CREW, PERSONNEL
CHF FD COMPUTER, FDC CREW, PERSONNEL
FDO, FDC CREW, PERSONNEL
DRIVER, PERSONNEL
BTRY PERSONNEL, PERSONNEL
NBC NCO, PERSONNEL
1ST SGT, PERSONNEL
BTRY CO, PERSONNEL
LOADER, PERSONNEL
GUNNER, PERSONNEL
GUN SECT CHF, PERSONNEL
GUN SECT CHF1, PERSONNEL
GUN SECT CHF2, PERSONNEL
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PLT VRC-46, SRADIO
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HOWITZER, GUNMOBILITY
CARRIER CARGO, TRUCK
AIMING CIRCLE, AIMING DEVICE
LAYING GUN, GUNELEC
PLOTING EQP, GUNELEC
BCS, TDS
FDC COMPUTER, TDS

AIMING STAKE, AIMING DEVICE
 COLLIMATOR, CALC ÉjÉAIM GUNS, GUNELEC
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 GUN SECT CHF1, 1552.00, 4360.96, -1.00, 1, 1, 2, 4, 1, 2
 GUN SECT CHF2, 1552.00, 4360.96, -1.00, 1, 1, 2, 4, 1, 2
 CARRIER CARGO, 1152.00, 4360.96, 1.00, 1, 1, 1, 1, 1, 2
 GUN COMMO VOICE, 1550.00, 4360.96, 1.00, 1, 1, 1, 1, 1, 2
 GUN COMMO DATA, 1550.00, 4360.96, 1.00, 1, 1, 1, 1, 1, 2
 GDU, 1550.00, 4360.96, 1.00, 1, 1, 1, 3, 1, 2
 AIM GUNS , 1550.00, 4360.96, 1.00, 1, 1, 1, 1, 1, 2
 COLLIMATOR, 1550.00, 4360.96, 1.00, 1, 1, 1, 1, 1, 2
 LAYING GUN, 1550.00, 4360.96, 1.00, 1, 1, 1, 1, 1, 2
 AIMING STAKE, 1550.00, 4360.96, 2.00, 1, 1, 1, 1, 1, 2
 AIMING CIRCLE, 1550.00, 4360.96, 2.00, 1, 1, 1, 1, 1, 2
 DRIVER, 1550.00, 4360.96, 1.00, 1, 1, 4, 4, 1, 2
 GUNNER, 1550.00, 4360.96, 1.00, 1, 1, 4, 4, 1, 2
 GUNNER1, 1550.00, 4360.96, -1.00, 1, 1, 4, 4, 1, 2

LOADER 1550.00, 4360.96,1.00, 1, 1, 3, 4, 1, 2
 LOADER1 1550.00, 4360.96,-1.00, 1, 1, 3, 4, 1, 2
 LOADER2 1550.00, 4360.96,-1.00, 1, 1, 3, 4, 1, 2
 HOWITZER , 1650.00, 4460.96,1.00, 1, 1, 1, 1, 1, 2
 CARRIER CARGO, 1252.00, 4460.96,1.00, 1, 1, 1, 1, 1, 2 ÉjÉGUN
 SECT CHF, 1650.00, 4460.56,1.00, 1, 1, 2, 4, 1, 2
 GUN SECT CHF1, 1650.00, 4460.56, -1.00, 1, 1, 2, 4, 1, 2
 GUN SECT CHF2, 1650.00, 4460.56, -1.00, 1, 1, 2, 4, 1, 2
 GUN COMMO VOICE, 1650.00, 4460.96,1.00, 1, 1, 1, 1, 1, 2
 GUN COMMO DATA, 1650.00, 4460.96,1.00, 1, 1, 1, 1, 1, 2
 GDU, 1650.00, 4460.96,1.00, 1, 1, 1, 3, 1, 2
 AIM GUNS , 1650.00, 4460.96,1.00, 1, 1, 1, 1, 1, 2
 COLLIMATOR, 1650.00, 4460.96,1.00, 1, 1, 1, 1, 1, 2
 LAYING GUN, 1650.00, 4460.96,1.00, 1, 1, 1, 1, 1, 2
 AIMING STAKE, 1650.00, 4460.96,1.00, 1, 1, 1, 1, 1, 2
 AIMING CIRCLE, 1650.00, 4460.96, 2.00, 1, 1, 1, 1, 1, 2
 DRIVER, 1650.00, 4460.96,1.00, 1, 1, 4, 4, 1, 2
 GUNNER, 1650.00, 4460.96,1.00, 1, 1, 4, 4, 1, 2
 GUNNER1, 1650.00, 4460.96,-1.00, 1, 1, 4, 4, 1, 2
 LOADER 1650.00, 4460.96,1.00, 1, 1, 3, 4, 1, 2
 LOADER1 1650.00, 4460.96,-1.00, 1, 1, 3, 4, 1, 2
 LOADER2 1650.00, 4460.96,-1.00, 1, 1, 3, 4, 1, 2
 HOWITZER , 1750.00, 4410.96,1.00, 1, 1, 1, 1, 1, 2
 CARRIER CARGO, 1752.00, 4010.96,1.00, 1, 1, 1, 1, 1, 2
 GUN SECT CHF2, 1750.00, 4410.56, -1.00, 1, 1, 2, 4, 1, 2
 GUN SECT CHF1, 1750.00, 4410.56, -1.00, 1, 1, 2, 4, 1, 2
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 AIM GUNS , 1750.00, 4410.96,1.00, 1, 1, 1, 1, 1, 2
 COLLIMATOR, 1750.00, 4410.96,1.00, 1, 1, 1, 1, 1, 2
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 AIMING CIRCLE, 1750.00, 4410.96, 2.00, 1, 1, 1, 1, 1, 2
 DRIVER, 1750.00, 4410.96,1.00, 1, 1, 4, 4, 1, 2
 GUNNER, 1750.00, 4410.96,1.00, 1, 1, 4, 4, 1, 2
 GUNNER1, 1750.00, 4410.96,-1.00, 1, 1, 4, 4, 1, 2
 LOADER1750.,4410.96,1.00, 1, 1, 3, 4, 1, 2
 LOADER11750.,4410.96,-1.00, 1, 1, 3, 4, 1, 2
 LOADER21750.,4410.96,-1.00, 1, 1, 3, 4, 1, 2
 HOWITZER , 1900.00, 4510.96,1.00, 1, 1, 1, 1, 1, 2
 CARRIER CARGO, 1902.00, 4110.96,1.00, 1, 1, 1, 1, 1, 2
 LOADER 1902.00, 4510.96,1.00, 1, 1, 3, 1, 1, 2
 LOADER1 1902.00, 4510.96,-1.00, 1, 1, 3, 1, 1, 2
 LOADER2 1902.00, 4510.96,-1.00, 1, 1, 3, 1, 1, 2
 GUN SECT CHF, 1900.00, 4510.56,1.00, 1, 1, 2, 4, 1, 2
 GUN SECT CHF1, 1900.00, 4510.56, -1.00, 1, 1, 2, 4, 1, 2
 GUN SECT CHF2, 1900.00, 4510.56, -1.00, 1, 1, 2, 4, 1, 2
 GUN COMMO VOICE, 1900.00, 4510.96,1.00, 1, 1, 1, 1, 1, 2
 GUN COMMO DATA, 1900.00, 4510.96,1.00, 1, 1, 1, 1, 1, 2
 GDU, 1900.00, 4510.96,1.00, 1, 1, 1, 3, 1, 2

AIM GUNS , 1900.00, 4510.96,1.00, 1, 1, 1, 1, 1, 2
 COLLIMATOR, 1900.00, 4510.96,1.00, 1, 1, 1, 1, 1, 2
 LAYING GUN, 1900.00, 4510.96,1.00, 1, 1, 1, 1, 1, 2
 AIMING STAKE, 1900.00, 4510.96,1.00, 1, 1, 1, 1, 1, 2
 AIMING CIRCLE, 1900.00, 4510.96, 2.00, 1, 1, 1, 1, 1, 2
 DRIVER, 1900.00, 4510.96,1.00, 1, 1, 4, 4, 1, 2
 GUNNER, 1900.00, 4510.96,1.00, 1, 1, 4, 4, 1, 2 ÉjÉGUNNER1,
 1900.00, 4510.96,-1.00, 1, 1, 4, 4, 1, 2
 BTRY PHONE, 3050.00, 3997.28,1.00, 1, 1, 1, 2, 1, 2
 BTRY PHONE, 1250.00, 3997.28,2.00, 1, 1, 1, 2, 1, 2
 BTRY PRC-68, 1250.00, 3997.28,1.00, 1, 1, 1, 2, 1, 2
 BTRY VRC-46, 1250.00, 3997.28,1.00, 1, 1, 1, 2, 1, 2
 BTRY VRC-46, 3050.00, 3997.28,1.00, 1, 1, 1, 2, 1, 2
 BTRY GRC-160, 3050.00, 3997.28,1.00, 1, 1, 1, 2, 1, 2
 BTRY CO 3050.00, 3997.28,1.00, 1, 1, 7, 1, 1, 2
 1ST SGT 1250.00, 3997.28,1.00, 1, 1, 7, 1, 1, 2
 NBC NCO 1250.00, 3997.28,1.00, 1, 1, 7, 1, 1, 2
 BTRY PERSONNEL, 1250.00, 3997.28,7.00, 1, 1, 7, 1, 1, 2
 DRIVER, 3050.00, 3997.28,1.00, 1, 1, 1, 1, 1, 2
 M577, 256.83, 4100.29,1.00, 1, 1, 1, 1, 1, 2
 BCS, 256.83, 4100.29,1.00, 1, 1, 1, 1, 1, 2
 PLOTTING EQP, 256.83, 4100.29,1.00, 1, 1, 1, 4, 1, 2
 FDC COMMO , 256.83, 4100.29,-1.00, 1, 1, 1, 4, 1, 2
 FDC VRC-46, 256.83, 4100.29,3.00, 1, 1, 1, 4, 1, 2
 FDC PRC-68, 256.83, 4100.29,1.00, 1, 1, 1, 4, 1, 2
 FDC PHONE , 256.83, 4100.29,4.00, 1, 1, 1, 4, 1, 2
 PLT PRC-68, 256.83, 4100.29,1.00, 1, 1, 1, 4, 1, 2
 PLT VRC-46, 256.83, 4100.29,1.00, 1, 1, 1, 4, 1, 2
 CHF FD COMPUTER, 256.83, 4100.29,1.00, 1, 1, 5, 5, 4, 2
 FA FD CREW, 256.83, 4100.29,4.00, 1, 1, 1, 5, 4, 2
 M577 DRIVER, 256.83, 4100.29,1.00, 1, 1, 1, 5, 4, 2
 PLT LDR 256.83, 4100.29,1.00, 1, 1, 1, 5, 4, 2
 PLT SGT 256.83, 4100.29,1.00, 1, 1, 1, 5, 4, 2
 PLT DRIVERS, 256.83, 4100.29,2.00, 1, 1, 1, 5, 4, 2
 FDC RADIO , 256.84, 4100.27,-1.00, 1, 1, 1, 1, 1, 2
 FDO CALCULATOR, 256.84, 4100.27,-1.00, 1, 1, 5, 1, 1, 2
 FA FD CREW COMPTR , 256.84, 4100.27,-1.00, 1, 1,10, 1, 1, 2
 FDO MANUAL, 256.84, 4100.27,-1.00, 1, 1, 9, 1, 1, 2
 FA FD CREW MANUAL , 256.84, 4100.27,-1.00, 1, 1,10, 1, 1, 2
 AUTHORITY , 256.84, 4100.27,-1.00, 1, 1, 7, 1, 1, 2
 M577, 1707.01, 4128.97,1.00, 1, 1, 1, 1, 1, 2
 BCS, 1707.01, 4128.97,1.00, 1, 1, 1, 1, 1, 2
 PLOTTING EQP, 1707.01, 4128.97,1.00, 1, 1, 1, 4, 1, 2
 FDC COMMO , 1707.01, 4128.97,-1.00, 1, 1, 1, 4, 1, 2
 FDC VRC-46, 1707.01, 4128.97,3.00, 1, 1, 1, 4, 1, 2
 FDC PRC-68, 1707.01, 4128.97,1.00, 1, 1, 1, 4, 1, 2
 FDC PHONE , 1707.01, 4128.97,4.00, 1, 1, 1, 4, 1, 2
 PLT PRC-68, 1707.01, 4128.97,1.00, 1, 1, 1, 4, 1, 2
 PLT VRC-46, 1707.01, 4128.97,1.00, 1, 1, 1, 4, 1, 2
 FDO, 1707.01, 4128.97,1.00, 1, 1, 5, 5, 4, 2
 CHF FD COMPUTER, 1707.01, 4128.97,1.00, 1, 1, 5, 5, 4, 2
 FA FD CREW, 1707.01, 4128.97,4.00, 1, 1, 1, 5, 4, 2

M577 DRIVER, 1707.01, 4128.97,1.00, 1, 1, 1, 5, 4, 2
 PLT LDR 1707.01, 4128.97,1.00, 1, 1, 1, 5, 4, 2
 PLT SGT 1707.01, 4128.97,1.00, 1, 1, 1, 5, 4, 2
 PLT DRIVERS, 1707.01, 4128.97,2.00, 1, 1, 1, 5, 4, 2
 FDC RADIO , 1707.02, 4128.94,-1.00, 1, 1, 1, 1, 1, 2
 FDO CALCULATOR, 1707.02, 4128.94,-1.00, 1, 1, 5, 1, 1, 2
 FA FD CREW COMPTR , 1707.02, 4128.94,-1.00, 1, 1,10, 1, 1, 2
 FDO MANUAL, 1707.02, 4128.94,-1.00, 1, 1, 9, 1, 1, 2
 FA FD CREW MANUAL , 1707.02, 4128.94,-1.00, 1, 1,10, 1, 1, 2
 ÉJÉAUTHORITY , 1707.02, 4128.94,-1.00, 1, 1, 7, 1, 1, 2
 FDC COMPUTER, 256.83, 4100.29,-1.00, 1, 1, 1, 1, 1, 2
 FDC COMPUTER, 1707.01, 4128.97,-1.00, 1, 1, 1, 1, 1, 2
 M577 583.37, 2974.62, 2.00, 1, 1, 1, 1, 1, 2
 END

LINKS

#REPAIR LINKS

SP FA AUTO MECH,4.,100,4.

\$SVC TM CHIEF

\$T,0.

\$E,1.

FA WEAPONS MECH,2.,100,2.

\$SVC TM CHIEF

\$T,0.

\$E,.7

SP FA SYSTEM MECH,1.,100,1.

\$SVC TM CHIEF

\$T,0.

\$E,.7

#REPAIR SUBCHAINS

MED,2.

\$MECH

\$T,0.

\$E,1.

LIGHT,2.

\$CREW

\$T,0.

\$E,1.

HOWITZER,8.,100,8.

GUNNER,8.,100,8.

\$GUN SECT CHF

\$T,0.

\$E,1.

GUN SECT CHF,8.,100,8.

\$GUNNER

\$T,0.

\$E,1.

LOADER,8.,100,8.

\$DRIVER

\$T,0.

\$E,1.

GUN SECT CHF1,8.,70,8.

\$GUN SECT CHF

\$T,0.
 \$E,1.
 GUN SECT CHF2,8.,50,8.
 \$GUN SECT CHF
 \$T,0.
 \$E,1.
 GUNNER1,8.,70,8.
 \$GUNNER
 \$T,0.
 \$E,1.
 LOADER1,8.,50,8. ÉjÉ\$LOADER
 \$T,0.
 \$E,1.
 LOADER2,8.,30,8.
 \$LOADER
 \$T,0.
 \$E,1.
 DRIVER,8.,30,8.
 AIM GUNS,8.,100,8.
 \$COLLIMATOR,AIMING STAKE
 \$T,0.,0.
 \$E,1.0,.50#CHANGED FROM .75 TO .50
 LAYING GUN,8.,100,8.
 \$AIMING CIRCLE#MANUAL BACKUP
 \$T,0.
 \$E,.5
 GDU,8.,100,8.
 FDC COMPUTER,1.,100,2.
 \$BCS
 \$T,0.
 \$E,1.
 FDO CALCULATOR,1.,100,1.
 \$FDO,PLT LDR,PLT SGT,CHF FD COMPUTER,GUN SECT CHF
 \$T,0.,5.,5.,0.,15.
 \$E,1.,1.,1.,1.,.5
 FA FD CREW COMPTR,1.,100,1.
 \$FA FD CREW,FDO,PLT LDR,PLT SGT,CHF FD COMPUTER,GUN SECT CHF
 \$T,0.,0.,5.,5.,0.,15.
 \$E,1.,1.,1.,1.,1.,.7
 GUN COMMO VOICE,8.,100,8.
 \$M,90
 GUN COMMO DATA,8.,100,8.
 \$M,50
 NO COMMO,1.,40,1.
 \$M,40
 \$DRIVER
 \$T,0.
 \$E,1.
 \$M,40
 FDC COMMO,1.,80,1.
 \$FDC PHONE,FDC PRC-68
 \$T,0.,0.

\$E,1.,.8
 FDO MANUAL,1.,80,2.
 \$FDO,PLT LDR,PLT SGT,CHF FD COMPUTER,GUN SECT CHF
 \$T,0.,5.,5.,0.,15.
 \$E,1.,1.,1.,1.,.5
 FA FD CREW MANUAL,3.,80,3.
 \$M,1.,0
 \$FA FD CREW,FDO,PLT LDR,PLT SGT,CHF FD COMPUTER,GUN SECT CHF
 \$T,0.,0.,5.,5.,0.,15.
 \$E,1.,1.,1.,1.,1.,.7
 FDC RADIO,1.,75,1.
 \$M,0.,0 ÉjÉ\$FDC VRC-46,PLT VRC-46
 \$T,0.,0.
 \$E,1.,1.
 AUTHORITY,1.,75,1.
 \$M,0.,0
 \$FDC CREW,PLT CREW
 \$T,0.,0.
 \$E,1.,1.
 \$M,0.,65
 CARRIER CARGO,4.,100,8.
 #ONLY NEED 1/2 AT EACH LOCATION
 \$M,0.,50
 M577,2.,100,2.
 \$M,0.,50
 END
 SUBCHAIN
 *1,GDU,FDC COMPUTER,FDO CALCULATOR,FA FD CREW COMPTR
 *2,FDC COMMO,FDO MANUAL,FA FD CREW MANUAL
 *3,FDC RADIO,AUTHORITY
 *4,AIM GUNS,LAYING GUN
 *5,GUN COMMO VOICE,GUN COMMO DATA
 *6,GUN SECT CHF,GUNNER,LOADER
 *7,GUN SECT CHF1,GUNNER1
 *8,GUN SECT CHF2,LOADER1
 *9,LOADER2,DRIVER
 END
 ORLINK
 +1,*1,*2,*3#FDC ORLINK
 +2,*6,*7,*8,*9#CREW ORLINK
 +3,*5, NO COMMO#GUN COMMUNICATIONS ORLINK
 END
 CHAINS
 +1,+2,HOWITZER,*4,+3
 \$CARRIER CARGO,M577
 END
 TOXIC LETHALITY
 END
 DELIVERY ERROR
 CHM12MG, 0., 104.,0.,133.,0.,0.
 END
 VOLLEY

CHM12MG, 0.,997.,4446.5,0.,18,0.,1800.
END
HEADING
M109 FOR TIM COWLES
END
INTERNAL
15.,30.,360.
END
OUTPUT
SUMMARY, PERSONNEL, HOWITZER, TDS, GUNELEC, SRADIO
DUMP9, ON
END
CONTAMINATED USAGE ÉjÉALL
END
REPLICATION
50
END
RECONSTITUTION EVENTS
5.,60.,120.,720.,1440.
END
DEGRADATION
2,1,1.
2,2,1.
2,3,1.
2,4,1.
2,5,1.
2,6,1.
2,7,1.
2,8,1.
2,9,1.
2,10,1.
4,1,.7
4,2,.95
4,3,.7
4,4,.63
4,5,.63
4,6,.95
4,7,.95
4,8,1.
4,9,.63
4,10,.63
END
T.K.C.
DRIVER,1,1.
GUN CHIEF,2,1.
LOADER,3,1.
GUNNER,4,1.
FDO C,5,1.
FIRING PLT LDR,6,1.
BTRY CO,7,1.
CBR PERS,8,1.
FDO M,9,1.

FD SPEC,10,1.
END
ROUND YES
END
GO
STOP
~e
SENINFO::BM109:::::C;
::::::::::C
0
0

The Impact of Medical Interventions
to Sustain Operations of an
M109A2 Artillery Battery
in Southwest Asia

Contract No. MDA903-88-D-1000

April 1991

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Joppa, MD 21085

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**The Impact of Medical Interventions
to Sustain Operations of an
M109A2 Artillery Battery
in Southwest Asia**

1. INTRODUCTION

Military operations conducted in hot environments such as that found in Saudi Arabia are difficult at best due to a number of factors specific to that area of the world. The desert terrain and the intense thermal environment forces soldiers to drastically alter their mode of operations. Heat stress and dehydration become real threats to the ability of troops to operate in this area of the world.

Current doctrine, as provided in U.S. Army Field Manual 21-10, outlines measures designed to minimize heat stress casualties, such as acclimatizing personnel to high temperatures as gradually as possible, encouraging soldiers to drink up to 4 gallons per day, and implementing work/rest cycles when the mission permits. Work/Rest ratios are determined as a function of the existing heat conditions. The practicality of implementing these work/rest cycles in the field is questionable as it is difficult to foresee stopping in the midst of a firefight to rest. The consequences of not stopping to rest, however, may be equally severe.

Extreme thermal conditions are magnified on the combined effects battlefield. While chemical protective gear (Mission-Oriented Protective Posture - MOPP) is designed to protect the soldier from the effects of chemical munitions, it is extremely hot to wear and adds significantly to the likelihood of heat stress. While soldiers may avoid becoming a chemical casualty, under certain conditions they may find it impossible to avoid becoming a heat stress casualty.

In addition to concerns resulting from conducting operations in hot environments, such as that found in Southwest Asia, the threat of chemical warfare in that area cannot be ignored. Several Third World nations undoubtedly have the technology to produce and weaponize chemical agents. Some of these nations have recently used chemical munitions; at least one has threatened the use of chemical munitions in a military confrontation. The U.S. Army must be prepared to face the threats posed by the extreme thermal environment and the likelihood of a chemical war.

Medical chemical defense products and information products are currently available to assist in conducting operations in this kind of multi-threat environment. Work/rest cycles and water intake disciplines are recommended for dealing with operations in the heat. Current medical interventions for chemical agents include the use of Atropine plus 2-PAM for nerve

agent exposure along with the use of MOPP gear. Other medical interventions are being investigated with an eye towards possibly fielding these medical treatments in the future.

2. OBJECTIVE

The purpose of this study is twofold. First of all, the ability of a military unit to conduct operations in Southwest Asia was examined along with the effects of implementing various work disciplines in the field. Secondly, the study examined the effectiveness of various medical interventions for the treatment of chemical agent exposure.

3. DISCUSSION

In the course of conducting this analysis, three models were used to provide insight into the issues raised above. The Goldman-Givoni model was used to determine the impact of the thermal environment found in Southwest Asia on an individual's ability to avoid becoming a heat stress casualty. The resulting outputs were then used within the US Army Ballistic Research Laboratory's Army Unit Resiliency Analysis (AURA) methodology to model the impact of these thermal factors on unit performance. Finally, the Modular Chemical Assessment Structure (MCAS) methodology was to model the combined threats considered and the effects of the various medical interventions being examined. The MCAS outputs were also used as inputs to the AURA model in order to provide a comprehensive picture of the effects of operating in Southwest Asia in a combined-warfare scenario.

The methods used in this analysis are detailed below.

4. THERMAL FACTORS

4.1 The Goldman-Givoni Model

The Goldman-Givoni Model was used to predict core temperature and probability of casualty for soldiers operating in the thermally stressful environment expected in Southwest Asia. The Goldman-Givoni model is based on equations generated by work conducted at the U.S. Army Research Institute of Environmental Medicine (USARIEM) during the late 1960s and early 1970s by Baruch Givoni and Ralph Goldman. Currently, there are at least three implementations of this model being used for different purposes in different organizations. The implementation used for this study was that originally coded by Dr. Klopchik at the U.S. Army Ballistic Research Laboratory for use in the combat simulation model known as AURA (Army Unit Resiliency Analysis) and subsequently modified by analysts at Science Applications International Corporation.

The BRL implementation of the Goldman-Givoni model is written in Fortran 77. The foundation for the BRL implementation was the stand-alone FORTRAN model known as TCORE, described by Berlin, Stroschein, and Goldman, in 1975.¹ Initially, TCORE was used as a member of the AURA family of models to produce coefficients which were used as input values to the AURA model. TCORE has subsequently been modified and is now incorporated directly into the AURA model. This modified code has come to be called the BRL implementation of the Goldman-Givoni model. A verification of the model and a demonstration of its use was completed in April of this year.²

The Goldman-Givoni model accepts inputs describing the meteorological conditions, working metabolic rate, clothing worn, initial skin temperature, level of acclimatization and level of dehydration being considered. The model then uses these inputs to determine the expected equilibrium core temperature of a soldier and the resulting probability of casualty. The BRL implementation of Goldman-Givoni also produces a distribution of the times at which the casualties are expected to occur.

In order to examine the different work disciplines of interest, it was necessary to make some changes to the BRL implementation of Goldman-Givoni at SAIC. These modifications did not alter the calculations of equilibrium core temperature as used within the AURA model, but instead enhanced the model to provide a detailed tracking of core temperature over time. The SAIC version of Goldman-Givoni was used to produce AURA inputs for the modeling of work/rest cycles and other excursions considered as a part of this study. A full explanation of what was involved in these modifications is included later in this report.

Appendix A contains a listing of the Goldman-Givoni model as used at SAIC. Appendix B provides an example of typical inputs used for the model and some of the resulting outputs.

4.2 Meteorological Conditions in Southwest Asia

Meteorological Data collected in Dhahran, Saudi Arabia in July³ was used for this analysis and is shown in Table 1. As can be expected, conditions change over the course of the day. As such, five time periods are outlined in the table for use in the study, with the most severe conditions prevailing between 1100 and 1500 hours.

Table 1. Average Meteorological Data for Dhahran, Saudi Arabia in July

LOCAL TIME	WINDSPEED M/S	WET BULB °C	DRY BULB °C	WBGT °C	SOLAR WATTS
0000-0700	2.9	21.5	31.1	24.6	0
0700-1100	4.6	21.5	35.6	27.3	516
1100-1500	6.4	22.6	40.9	29.6	519
1500-1900	6.1	23.0	39.1	28.7	361
1900-2300	3.3	23.1	34.5	26.6	0
2300-2400	2.9	21.5	31.1	24.6	0

4.3 Levels of Acclimatization and Dehydration

In severe weather conditions such as those found in Southwest Asia, it is vital that troops have a chance to acclimatize themselves to the conditions in which they will be expected to operate. Unacclimatized troops find desert operations extremely difficult and likely to produce a high number of heat stress casualties. Given the chance to work in these conditions for at least twelve days, soldiers will have a much better chance of avoiding heat stress than those new to the environment.

In this hot environment, it is also essential that troops maintain a strict regiment of water intake. It is well known that most humans do not drink enough fluids to maintain their bodies at full hydration but, instead, typically maintain a level of 2% dehydration while going about their normal routines. Severe dehydration (around 7%) will likely result in death.

In order to examine what might be considered a worst case and a best case scenario for this study, two combinations of acclimatization/dehydration were considered. The best case scenario examined fully acclimatized troops dehydrated at 2% of their normal body fluid levels. The worst case scenario looked at the effects of deploying unacclimatized troops at 5% dehydration.

4.4 Work Disciplines

Three different work disciplines were considered for this analysis. To provide a baseline of comparison for the other work disciplines considered, continuous work with no formally established rest periods was included in the study. Secondly, the current doctrine specifying work/rest cycles (as outlined in

Army Field Manual 21-10) was modeled. Finally, a new work discipline was examined. This work discipline allowed soldiers to pace themselves over the course of the day, taking care not to allow their core temperatures to exceed a pre-determined level.

5. THREAT ASSESSMENT

5.1 Threat Scenario

The initial plan for the study was to model multiple chemical and conventional attacks in a hot environment typical of the Persian Gulf in July. The actual scenario was adapted from one used currently at the US Army Concepts Analysis Agency (USACAA) for their large, theater-level war gaming. Figure 1 shows the scenario planned for the study. The first scenario involved a Battalion Size Force arriving on Day 0 and facing conventional artillery attacks on Day 4 and 10, with chemical attacks occurring on Days 9 and 12. The first of the chemical attacks (on Day 9) was to be an artillery attack using the chemical agent known as HD (Soman). The second attack involved a bomb attack with GA (Mustard) and HD. The second scenario planned focused on a Brigade Size Force arriving on Day 8 and facing a conventional attack on Day 11 and chemical attacks (of GB and HD, respectively) on Days 9 and 13.

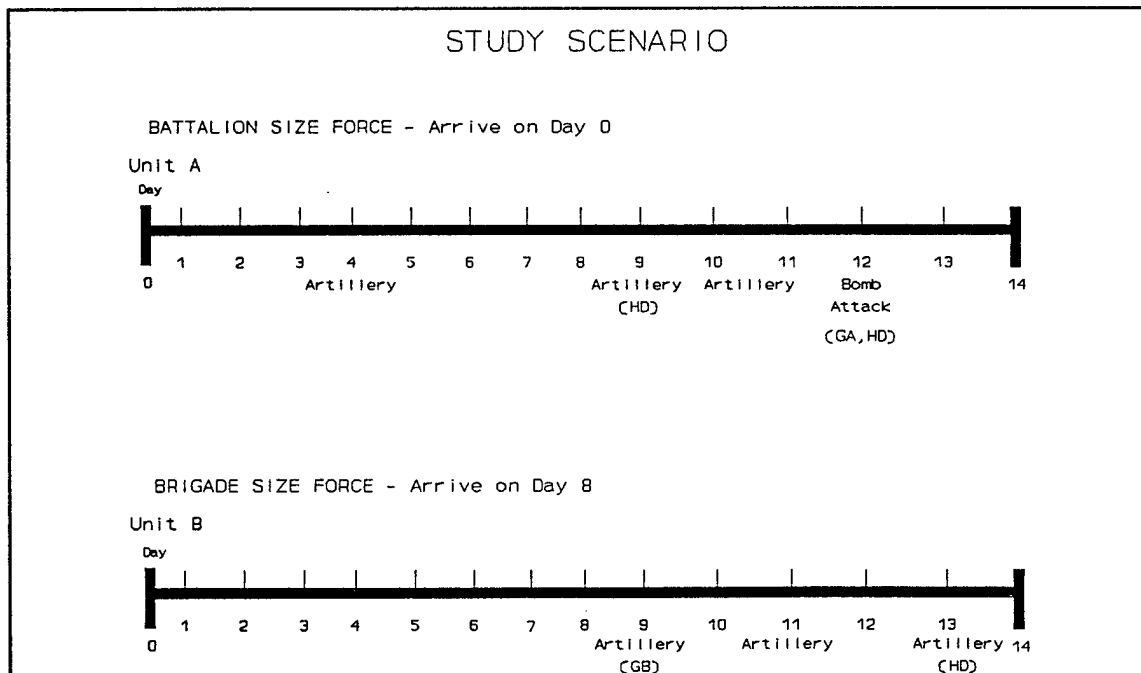


Figure 1. Threat Scenario for Study.

Due to time constraints, the effects of the conventional attacks were not considered in this study nor was the first scenario involving the attacks on Day 4 and 10. Early on in the study, a lot of time was spent determining a reasonable number of incoming conventional rounds which would produce a specified level of personnel casualties. Preliminary runs using the AURA model suggested seemingly unbelievable number of munitions required to achieve 10% personnel casualties. Upon closer examination of how AURA plays the incoming rounds, we were concerned about the fact that AURA assumed the same exact deployment of the unit between replications. Thus, using current conventional lethality data for the various personnel and equipment found in the unit, along with the appropriate data on delivery errors for the munitions considered, throughout many replications, few casualties were seen for as many as 1000 incoming artillery munitions. The reason was that many times, the delivery errors caused the rounds to miss the unit entirely. While this is not entirely unlikely, it is likely that a much different answer would surface if the unit were able to move between replications. So, given these concerns and considerable time constraints imposed, the conventional only attacks were omitted from the analysis.

The effects of the combined attacks were modeled using the Modular Chemical Assessment Structure (MCAS) model.⁴ Though the AURA model includes modules used to assess the effects of chemical agents, it was decided to play these effects off-line in MCAS because it was currently in use at SAIC and, as such, was able to be modified easily to incorporate the various medical interventions of interest and their effects on personnel casualties and time of return to duty.

5.2 The MCAS Model

In August of 1988, work to complete Task 3 of Delivery Order 1 of contract DAAA15-85-D-007 entitled CHEMCAS2 Development was completed and resulted in the creation of the Modular Chemical Assessment Structure (MCAS) model. This model combined the best features of CHEMCAS3, Yet Another CHEMCAS (YAC), IMPGEN and NUSSE3 (four existing models used the model chemical warfare), while enhancing the model with a more user-friendly interface and graphics.

Specifically, the CHEMCAS3 and YAC models were modularly included through the development of a target complex and a fireplan of weapon impacts with NUSSE3 used to generate agent dispersion and diffusion. In addition, technical improvements were incorporated into MCAS, including the representation of population distribution, alarm placement, and grid spacing options. Also, droplet dispersion was sampled logarithmically which gives a higher fidelity representation of the liquid pattern on the ground, an over simplification in the generation of the puff mass at the reference height was corrected and a

three dimensional orientation of the puff sources was implemented. Finally, a problem occurring in CHEMCAS3 and YAC in overlaying single munition patterns was corrected. The time phased evaporation of droplets from a particular point is affected by droplets that have been deposited from other munitions. The MCAS methodology explicitly computes the secondary evaporation problem based on the liquid droplet pattern on the ground from one or multiple munitions rather than summing individual munition secondary evaporation patterns on the overlaid grid locations.

5.3 Conventional Effects of Chemical Munitions

The toxicology of chemical warfare agents is an area with many unresolved issues due to the sparse human database. Difficulties in extrapolating data from animal models to estimates of expected human response are most evident for nerve agents. There have only been a very small number of experimental animal exposures of "injured" animals. There is no adequate basis for assessing the effects of "wounds" or the intoxication potential with a coincidental agent exposure. Another difficulty in assessing their toxicology issues is that there exists no data to assess the ability of chemical munition fragments to physically transport free or sorbed liquid agent into the wounds of a soldier hit by that fragment. In the absence of definitive data, the approach taken in this analysis was to assume that conventional effects did not facilitate the chemical effects and, by the same token, the chemical effects did not facilitate the conventional effects. Each would be handled as independent.

The conventional casualty effects were represented by a probability of casualty based on the distance from the munitions impact point. The MCAS model calculates the probability of casualties at each grid point of the target and then sums the effects for the entire target. To combine the chemical and conventional effects at each grid point, the conventional probability was subtracted from the probability of becoming a chemical casualty and should best be interpreted as the probability of becoming a conventional casualty with or without chemical effects. The chemical casualty probabilities therefore did not represent these personnel that also had conventional effects (see Figure 2). This artificial choice was made, in part, to ensure that no bias would be given to make the chemical munition look more effective. It was necessary to characterize the conventional effects of weapons made by different countries in different ways. For instance, the US-made GB shells and bombs were assembled with thin steel or aluminum shells which are 25% of the normal conventional high explosive shell fragmentation effects. The Soviet Union uses these same shell and bomb bodies for their chemical munitions as their conventional munitions. The burster:weight ratio of the shell remains essentially the same. Fragmentation pattern expectations have been reviewed by several sources. The conventional effects should be 80-100% of

the conventional round. This rule of thumb is only relevant in cases where the same basic casing and burster ratio are maintained. As shown in Figure 2, the assumption was made that the conventional effects would be 80% of the conventional effects of the conventional-only munition for prone and standing personnel.

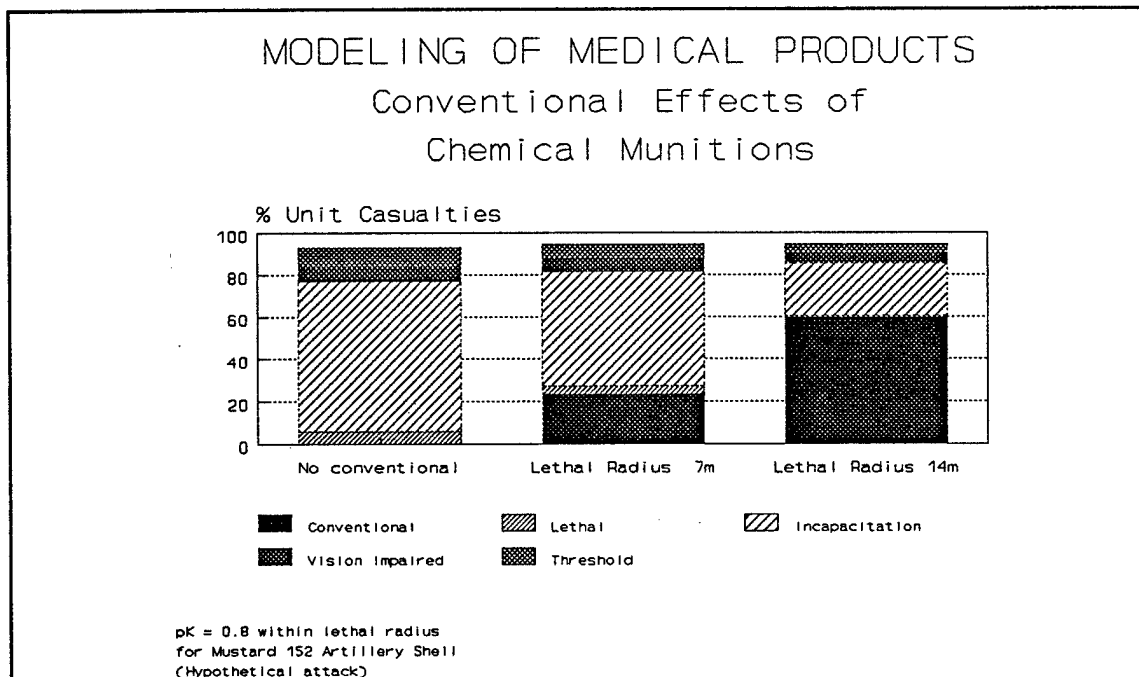


Figure 2. Comparison of chemical munitions effects with no conventional, 7 m lethal radius, and 14 m lethal radius.

It should be noted that the net effect of including conventional effects produced during a chemical attack reduces the chemical contamination expectations from the chemical fill. There is an effect on all the levels of chemical casualty but does not completely subsume all the lethal chemical effects. It is entirely possible with a 152 mm mustard artillery shell to have a portion of the population become chemical lethalties without having only conventional fragmentation wounds. It is also reasonable to expect that many of the people that would have been incapacitated on the target would, in fact, have conventional weapons wounds as well, independent of a combined chemical and conventional effect. If knowledge can be obtained in the future about what happens to people with wounds exposed to chemical agent hazards, then a more detailed picture of the phenomena can be obtained.

5.4 Medical Interventions Considered

Various medical interventions were considered for this analysis. They included no therapy (which served as a baseline

for the other cases), current therapy (Atropine plus 2-PAM for nerve agents), near-term therapy (Atropine plus 2-PAM plus Anticonvulsant plus Pyridostigmine for nerve agent), and far-term therapy (biotechnology product for nerve agent and topical protectant for nerve and blister agents). The different interventions were modeled within MCAS. The methodology used to model these interventions and their effects on probability of casualty and duration of effects is detailed in Appendix C.

6. UNIT PERFORMANCE

6.1 The AURA Model

The Army Unit Resiliency Analysis (AURA) methodology was developed to represent mission effectiveness. The model considers the combination of the assets available to a unit and the individual jobs which must be done correctly in a time sequence to appropriately complete a mission segment. The assets of a unit are selected based on the table of organization and equipment⁵ while the jobs are based upon the Army Training Evaluation Program (ARTEP) standards for essential tasks and the performance measure to be gained from the proper execution of the job.

6.2 The M109A2 Artillery Unit

The military unit chosen for this analysis was the M109A2 Self-Propelled Field Artillery 8-Gun Battery (part of the 3X8 Direct Support Field Artillery Battalion). This unit has been used in various AURA studies by both the US Army Ballistic Research Laboratory and SAIC.^{5,6} The original BRL inputs were adapted for use in this study.

The M109A2 Battery has many missions to perform on the battlefield. Of these missions, the unit's ability to conduct its firing mission was considered of most interest. The original BRL inputs modeled the battery firing both conventional and terminally guided (Copperhead) munitions. It is anticipated that one section per 4-Gun platoon will be designated to fire Copperhead rounds, leaving three sections for conventional fires. Consequently, the battery's firing mission was to fire 36 ICM/conventional rounds and 6 Copperhead rounds per 3 minutes of firing, reflecting firing rates of two and one round per minute per tube for the ICM/conventional and Copperhead munitions, respectively. Mission time included the units need to receive the fire mission, compute the necessary firing data, align the guns, load the ammunition and fire.

Other essential data used in describing the unit, such as the unit's deployment and task structure (links and chains in AURA nomenclature), was unmodified with the exception that the

ability of the unit to use cross-training was ignored. Thus, no substitution was made for personnel lost during the engagement.

6.3 Modeling of Thermal Effects in AURA

The effects of working in the thermally-stressed environment present in Southwest Asia were played directly in AURA through use of the AURA HEAT STRESS option. The meteorological conditions shown in Table 1 were input along with data describing clothing worn, work intensity (metabolic rate), percent of dehydration and days of acclimatization. Table 2 lists the clothing parameters used in the analysis,⁷ along with their wind correction factors.

Table 2. Clothing Parameters Used in AURA Analysis				
Type of Clothing	Clothing Parameters			
	Clo	Gamma	Im/Clo	Gamma
BDU ¹	1.13	0.26	0.43	0.38
BDO4 ²	1.68	0.255	0.21	0.49
MOPP1 ³	1.47	0.15	0.30	0.36

1. BDU - Battle Dress Uniform
2. BDO4 - Battle Dress Overgarment, Mask, Hood and Gloves, Closed.
3. MOPP1 - Battle Dress Overgarment Only, Closed.

Three levels of work intensity were considered: light, medium and heavy. The drivers in the unit were considered to be doing light work at a metabolic rate of 125 WATTS. The Gun Section Chiefs and Gunners were judged to be doing medium work at 250 WATTS, while the Loaders were performing heavy work at 425 WATTS.

According to the original BRL inputs for the M109A2 Artillery Battery, at each gun, one Gunner, one Gun Section Chief and one Loader are required to complete a successful firing mission. Completing that firing mission requires the personnel to work at the metabolic rates specified above. If all three of these jobs cannot be filled because of heat stress casualties, chemical casualties, or some other event, there are three alternate combinations of the required jobs which would result in a successful firing but not at the maximum firing rate.

Figure 3 shows the alternate pathways for completing the firing mission at each gun. The percentage shown is the maximum mission effectiveness possible when using that particular path to complete the firing mission. In the event that the Loaders job

could not be done by the loader, for example, the Gun Section Chief and the Gunner could accomplish the firing mission but could only be expected to perform the mission at a maximum of 70% percent effectiveness. When the Gun Section Chief and Gunner are performing the firing mission without the Loader, they can also be expected to be working at a somewhat different work intensity than that achieved when all jobs are being done. In order to account for the different metabolic rates expected when personnel were "filling in" for missing personnel, a algorithm was developed to estimate the metabolic rates of personnel in these positions. The algorithm accounted for the original metabolic rate required by the job to be performed and the metabolic rate of the job being covered by the other personnel. This algorithm and the resulting metabolic rates that were used in AURA are included in Appendix D.

100%	→	Gun Section Chief - Gunner - Loader
70%	→	Gun Section Chief - Gunner
50%	→	Gun Section Chief - Loader
30%	→	Loader - Driver

Figure 3. Alternate Pathways for Firing Mission.

6.4 Modeling of Chemical Effects and Medical Interventions in AURA

As explained previously, chemical effects and medical interventions were played within MCAS and provided as inputs to AURA via AURA's TEMPORARY LOSSES and RETURN TO DUTY options. Tables 3 and 4 list the chemical casualty data for the various medical interventions and the two different types of attacks considered. Also listed are the persistence time, and duration of effects for each medical intervention. For example, Table 1 shows that the GB attack, with no therapy and chemical protective gear being used, resulted in 89% of the unit sustaining threshold effects, 83% of the unit having some visual impairment which

would last for one day, 32% of the unit remaining incapacitated for ten days. These percentages are inclusive. In addition, 12% of the unit became lethalties.

Table 3. Chemical Effects Data for GB Attack on Day 1 of Scenario				
Persistence Time: 15 Minutes				
Medical Intervention	Percentage of Unit Effected (Duration of Effects)			
	Threshold	Visually Impaired	Incapacitated	Dead
No Therapy No MOPP	89	83 (1 Day)	32 (10 Days)	12
No Therapy BDO4 ¹	89	47 (1 Day)	13 (10 Days)	7
Current Therapy BDO4 ¹	62 (2 Days)	47 (2 Days)	13 (10 Days)	0
Near Term Therapy BDO4 ¹	62 (2 Days)	47 (2 Days)	3 (4 Days)	0
Far Term Therapy No MOPP	12 (2 Days)	12 (2 Days)	5 (3 Days)	0
Far Term Therapy BDO4 ¹	7 (2 Days)	7 (2 Days)	4 (3 Days)	0

1. Battle Dress Overgarment worn by troops during persistence of GB.

Table 4. Chemical Effects Data for HD Attack on Day 5 of Scenario

Persistence Time: 4 Hours Duration of Visual Impairment: 2 Days Duration of Incapacitation: 21 Days				
Medical Intervention	Percentage of Unit Effected			
	Threshold	Visually Impaired	Incapacitated	Dead
No Therapy No MOPP	85	15	8	0
No Therapy BDO4 ¹	54	0	0	0
Current Therapy BDO4 ¹	54	0	0	0
Near Term Therapy BDO4 ¹	53	0	0	0
Far Term Therapy No MOPP	85	8	4	0
Far Term Therapy BDO4 ¹	27	0	0	0

1. Battle Dress Overgarment worn by troops during persistence of HD.

6.5 Modeling of Work Disciplines

As mentioned earlier in this report, three work disciplines were examined in this study. They included continuous work, the implementation of work/rest cycles as specified in US Army Field Manual 21-10 and a new discipline allowing troops to pace themselves so as not to exceed a pre-determined core temperature and thus avoid becoming a heat stress casualty. Modeling continuous work within AURA was straightforward. Modeling the remaining work disciplines, however, required some modification to SAIC's Goldman-Givoni model. These modifications are described in detail in Appendix E.

Appendix F contains an example of the AURA inputs used for this analysis.

7. FINDINGS

The results of these analyses fall into two general categories. The first involve a comparison of the different work disciplines considered and their relative worth. Secondly, the results illustrate the potential benefits of the different medical interventions examined.

7.1 Work Disciplines

Figure 4 shows the results of comparing the various work disciplines considered, under the thermal conditions to be expected in Southwest Asia. Figure 4 illustrates the different levels of unit effectiveness expected over the course of the scenario. The effectiveness curves fall into two groups: those which reflect fully acclimatized troops at 2% dehydration and those which depict unacclimatized troops, fully dehydrated at 5%. Under the most optimistic conditions, the unit can best perform by either continuously working or by pacing themselves so as to maintain their core temperature at or below 39°C. In fact, the curves for these two cases are identical. At the extreme conditions, however, (unacclimatized, 5% dehydrated) maintaining a Tre (rectal temperature) limit of 39°C is clearly the best alternative.

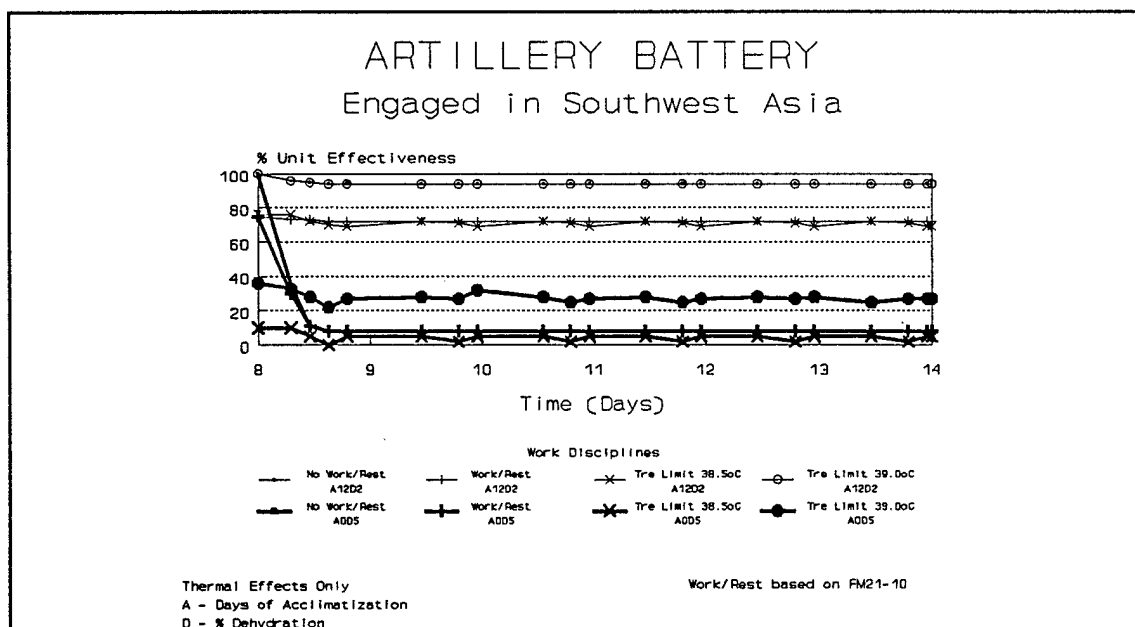


Figure 4. Artillery Unit Effectiveness, Thermal Effects Only.

Figures 5 and 6 contain the data on unit casualties and productivity for these cases. Here, productivity is a weighted average of the effectiveness values shown in Figure 5. Figure 6

shows unit casualties and productivity for fully acclimatized troops at 2% dehydration (referred to as the Best Case Scenario), while Figure 6 includes the same data for unacclimatized troops at 5% dehydration (Worst Case Scenario). Figure 5 illustrates that although unit casualties are essentially the same for all work disciplines considered under these conditions, unit productivity is greater for the continuous work and Tre limit at 39°C case. This is due to the amount of time required for rest in the work/rest case and the reduction in work intensity when attempting to maintain a Tre limit at 38.5°C.

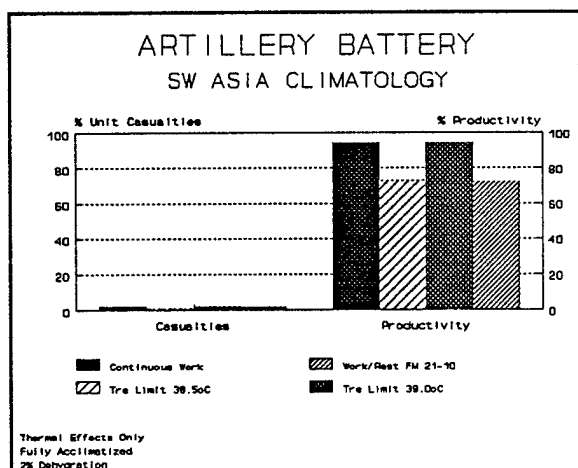


Figure 5. Unit Casualties and Productivity, Thermal Effects Only, Best Case Scenario

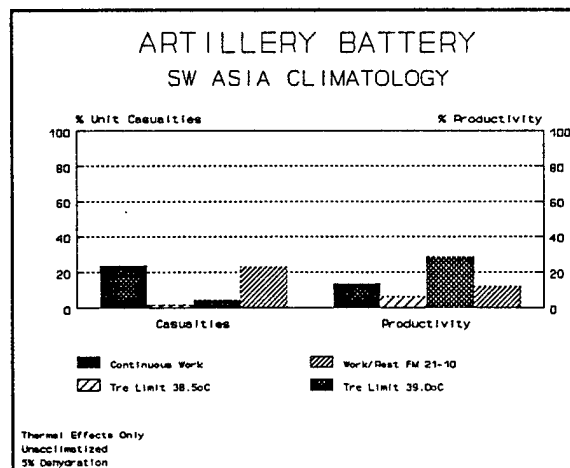


Figure 6. Unit Casualties and Productivity, Thermal Effects Only, Worst Case Scenario

Figure 6 makes a strong case for choosing the work discipline in which troops pace themselves so as to maintain a Tre limit at 39°C. This work discipline provides the fewest unit casualties for the greatest return in unit productivity. Figure 6 clearly shows that the work/rest cycles defined in Field Manual 21-10 are not accomplishing the goal of keeping casualties to a minimum. This goal is better achieved by the Tre Limit at 39°C alternative work discipline.

7.2 Medical Interventions

Figures 7 through 24 contain the results for comparison of the different medical interventions considered in this study. These figures are grouped according to medical intervention and consist of three graphs each: a graph of Unit Effectiveness over time and two graphs showing Unit Casualties and Productivity for the different acclimatization/dehydration cases. For example, Figures 7 through 9 include the results of using no therapy for the GB and HD attacks and of having the troops remain in BDUs during the attack. Note, productivity refers to how effectively the unit was able to perform over the course of the scenario.

ARTILLERY BATTERY Engaged in Southwest Asia

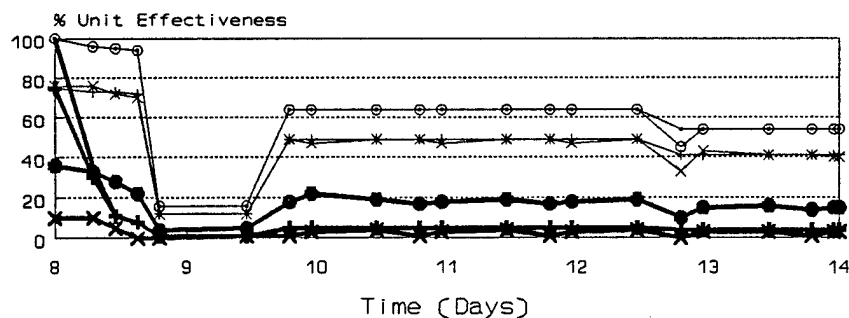


Figure 7. Artillery Unit Effectiveness, No Therapy/BDU Case

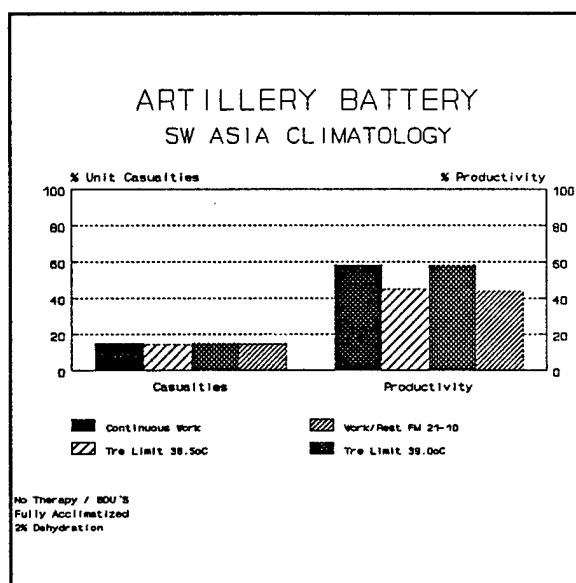


Figure 8. Unit Casualties and Productivity, No Therapy/BDUs, Best Case Scenario

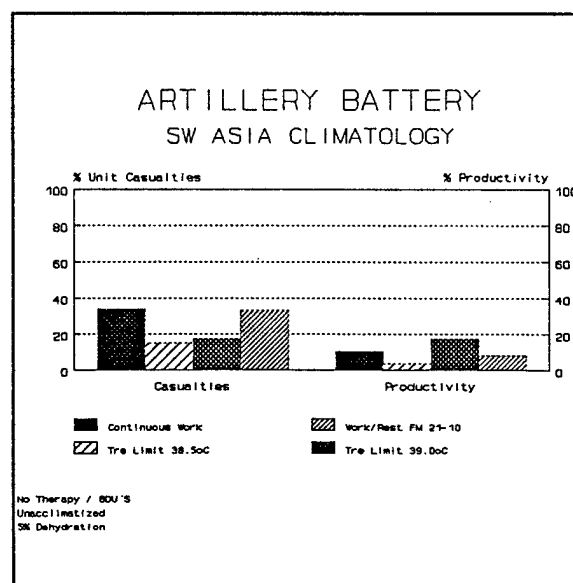


Figure 9. Unit Casualties and Productivity, No Therapy/BDUs, Worst Case Scenario

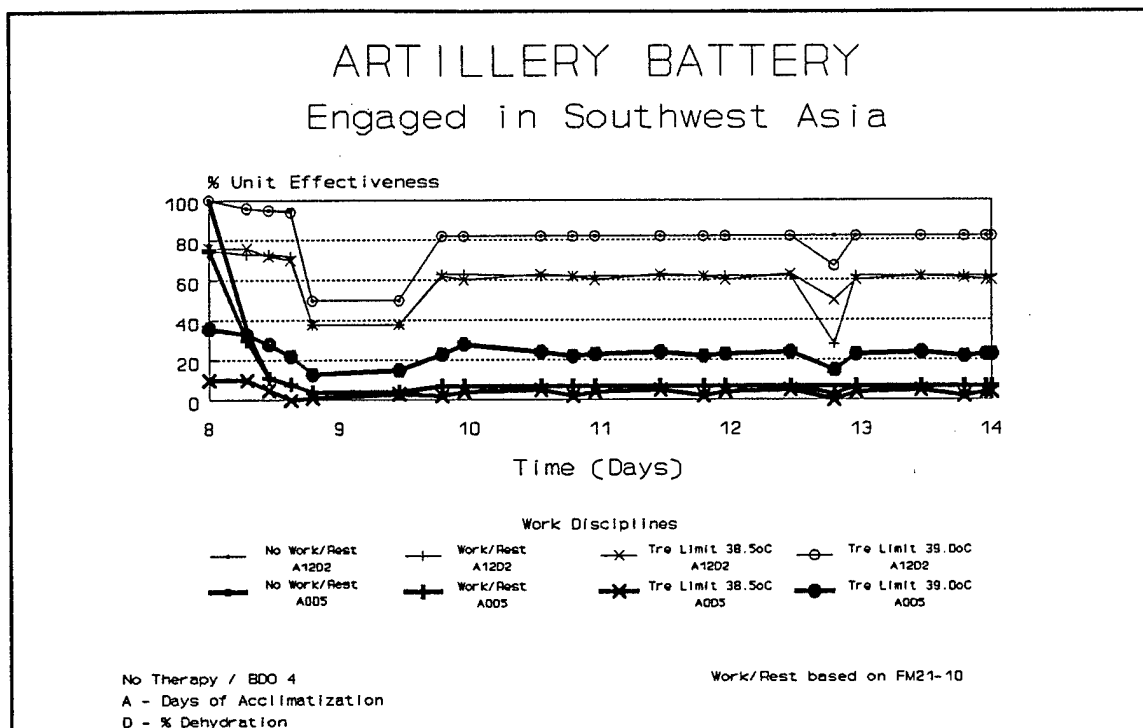


Figure 10. Artillery Unit Effectiveness, No Therapy/BD04 Case

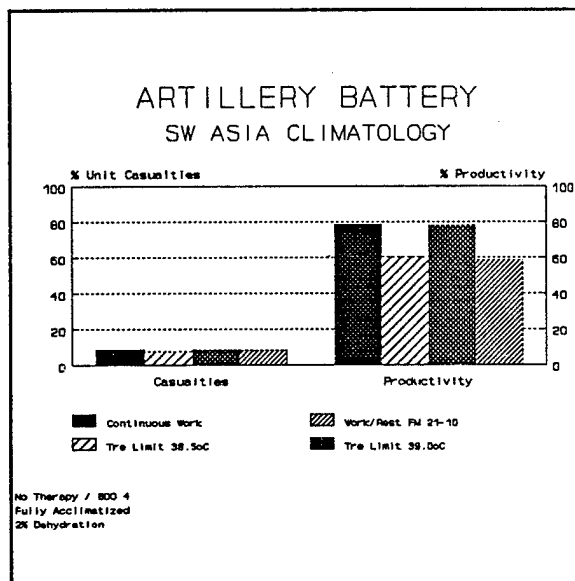


Figure 11. Unit Casualties and Productivity, No Therapy/BD04, Best Case Scenario

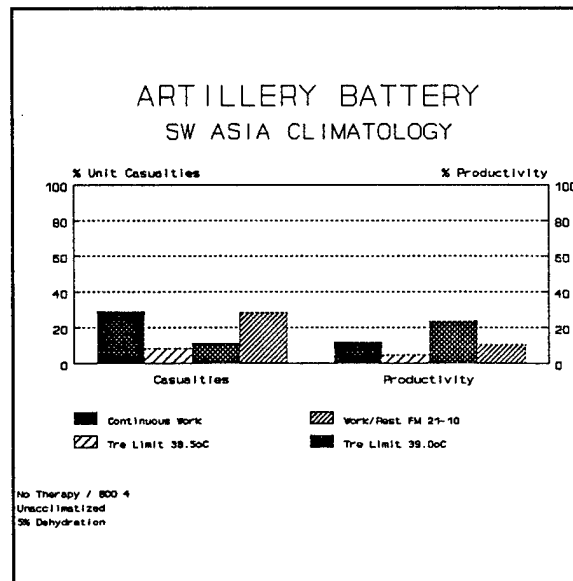
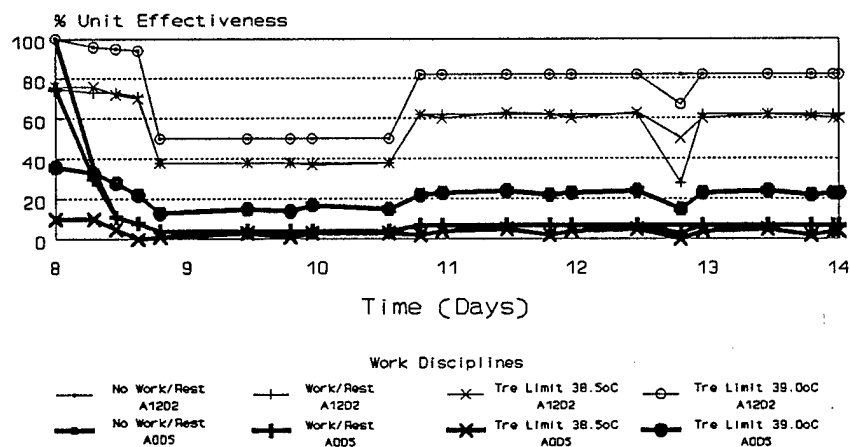


Figure 12. Unit Casualties and Productivity, No Therapy/BD04, Worst Case Scenario

ARTILLERY BATTERY Engaged in Southwest Asia



Current Therapy / BDO 4
A - Days of Acclimatization
D - % Dehydration

Work/Rest based on FM21-10

Figure 13. Artillery Unit Effectiveness, Current Therapy Case

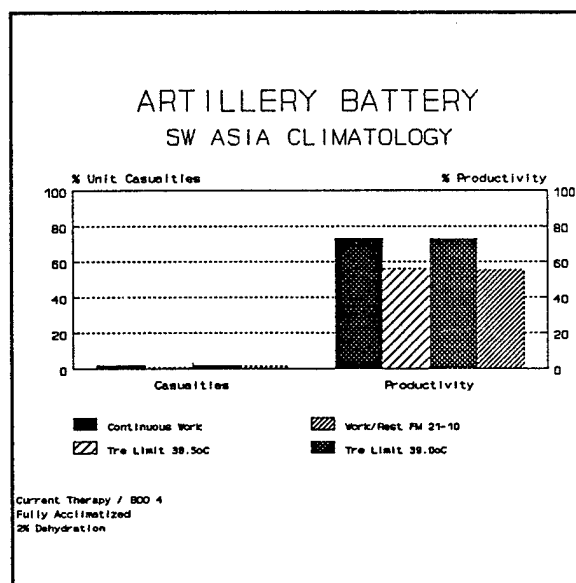


Figure 14. Unit Casualties and Productivity, Current Therapy, Best Case Scenario

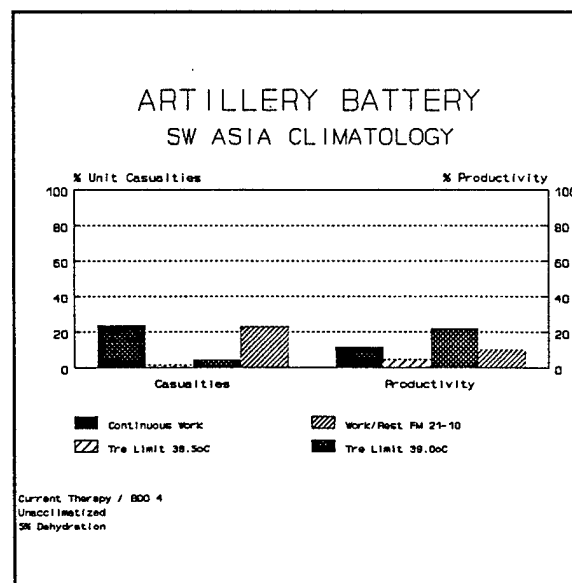


Figure 15. Unit Casualties and Productivity, Current Therapy, Worst Case Scenario

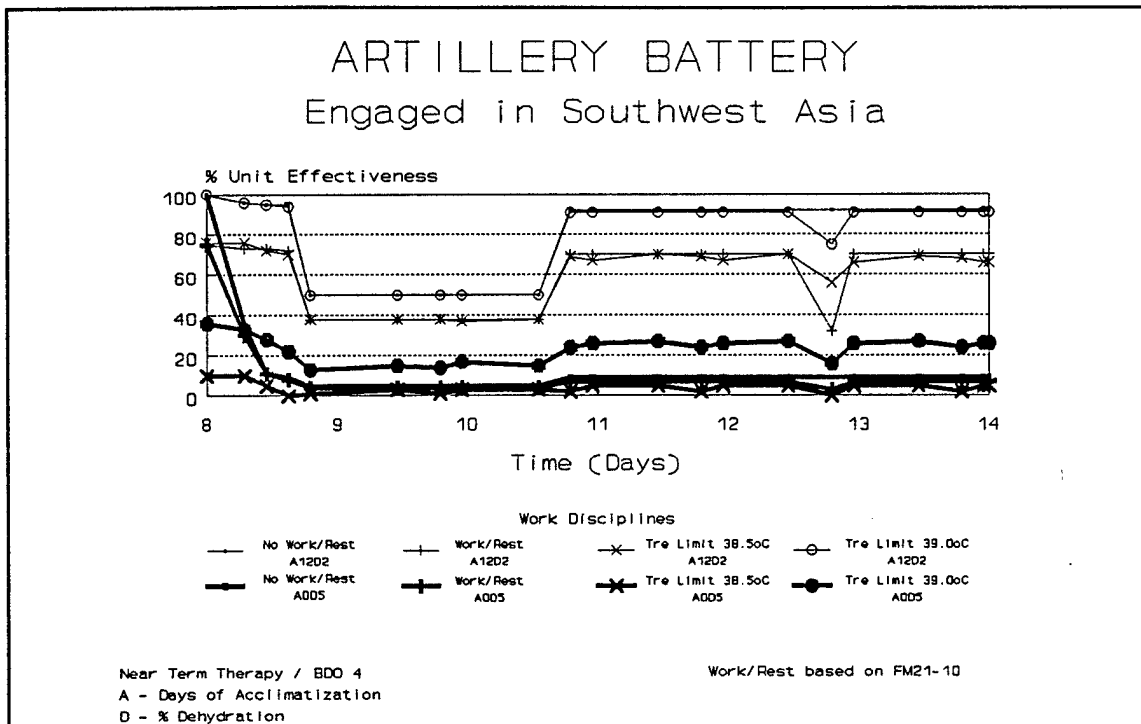


Figure 16. Artillery Unit Effectiveness, Near Term Therapy

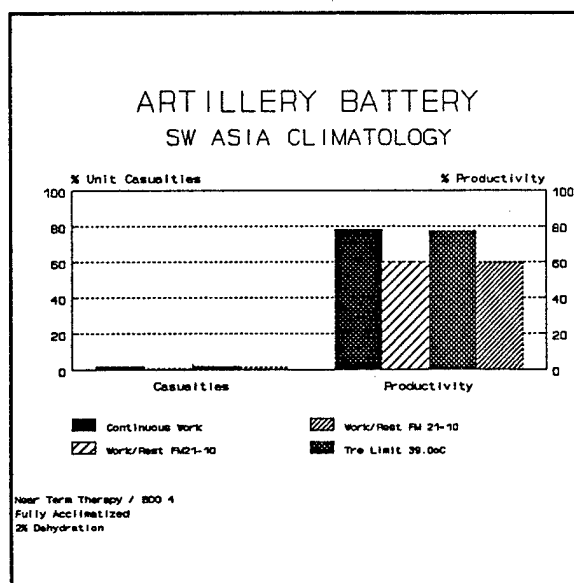


Figure 17. Unit Casualties and Productivity, Near Term Therapy, Best Case Scenario

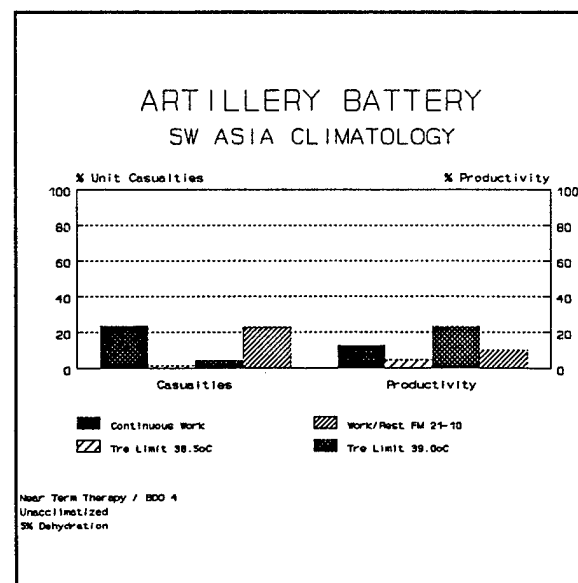


Figure 18. Unit Casualties and Productivity, Near Term Therapy, Worst Case Scenario

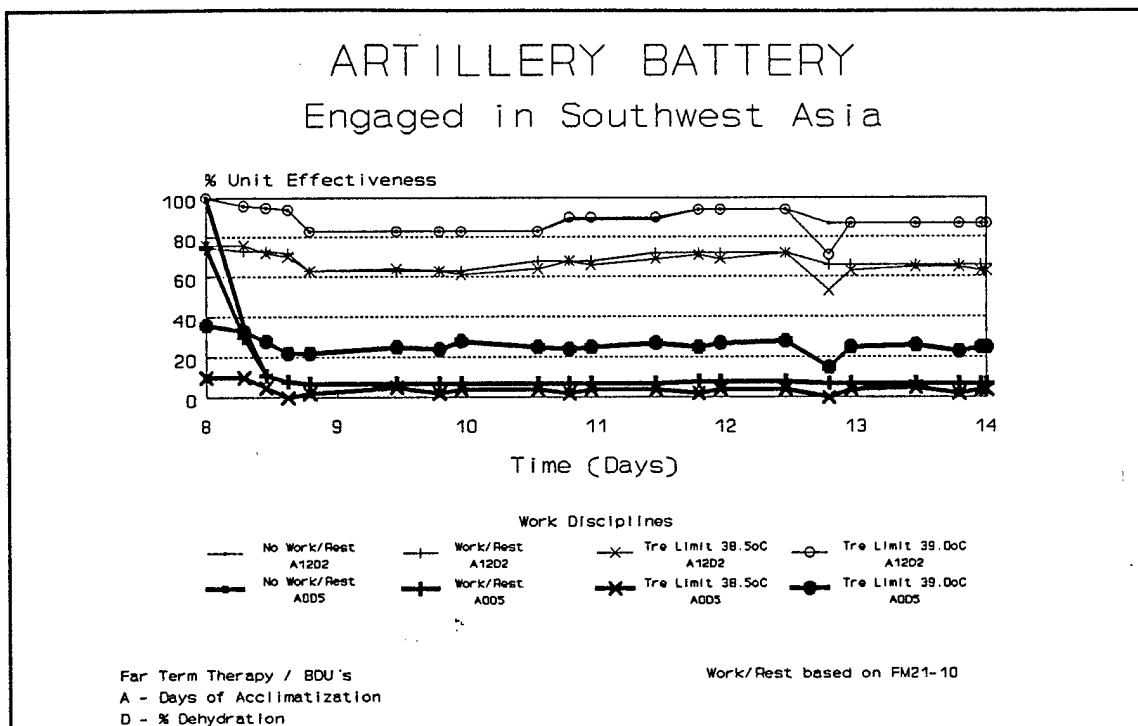


Figure 19. Artillery Unit Effectiveness, Far Term Therapy/BDUs

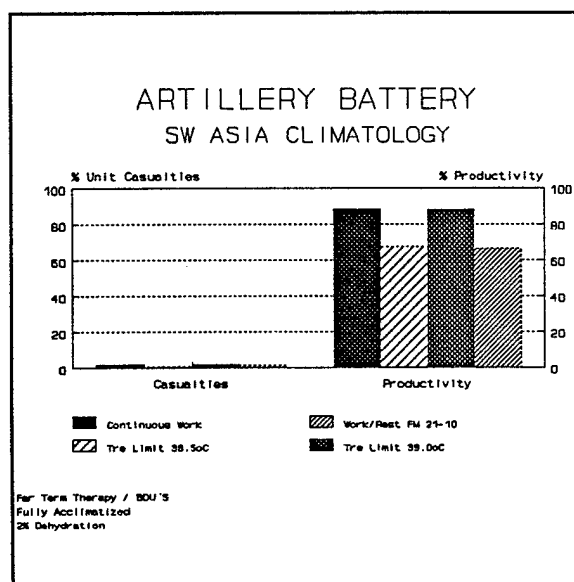


Figure 20. Unit Casualties and Productivity, Far Term Therapy/BDUs, Best Case Scenario

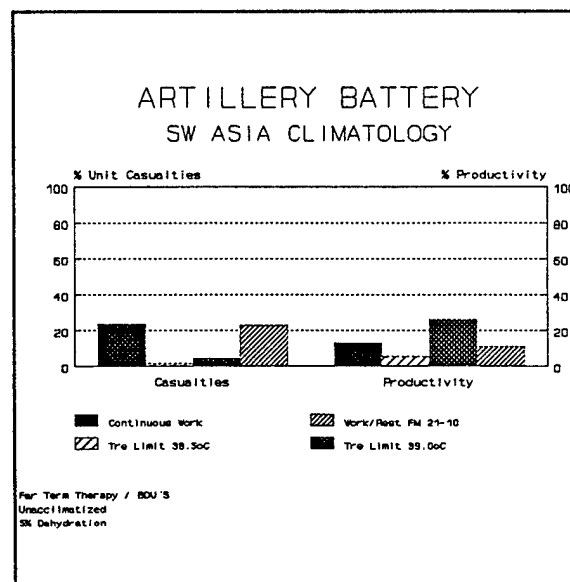


Figure 21. Unit Casualties and Productivity, Far Term Therapy/BDUs, Worst Case Scenario

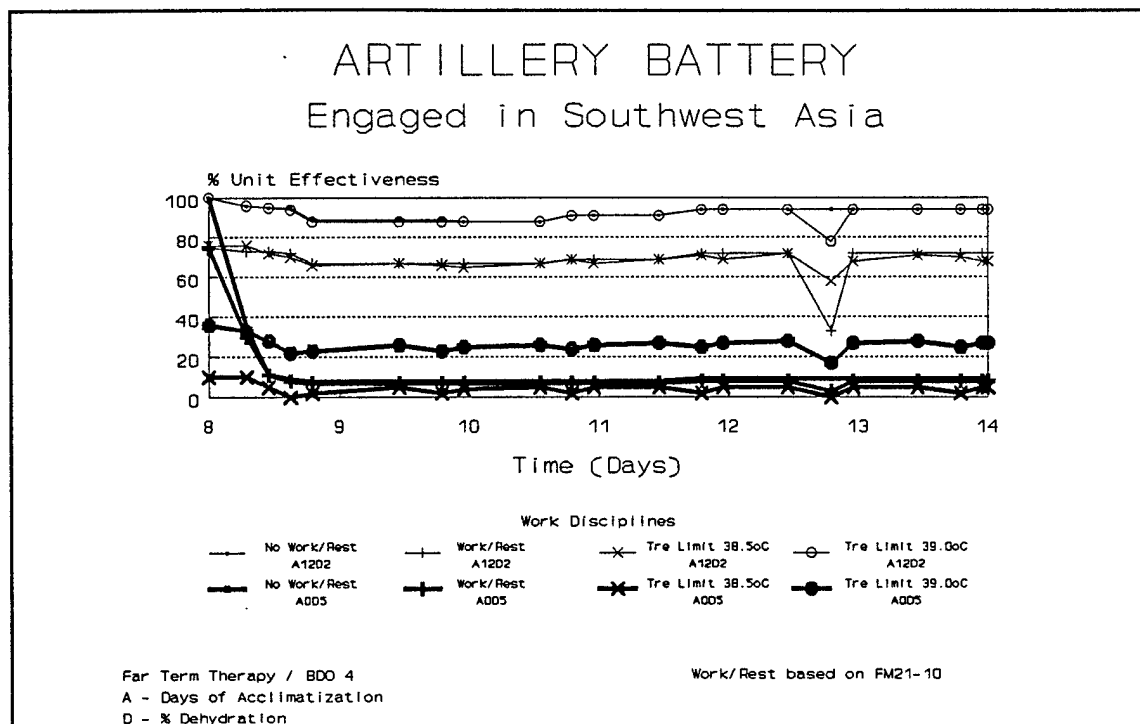


Figure 22. Artillery Unit Effectiveness, Far Term Therapy/BDO4

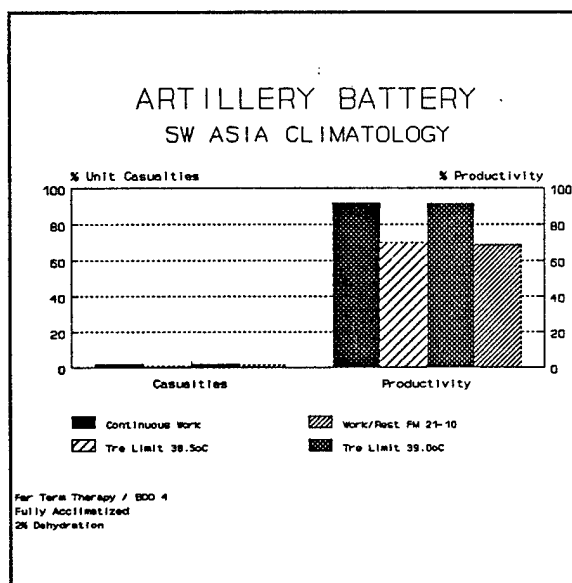


Figure 23. Unit Casualties and Productivity, Far Term Therapy/BDO4, Best Case Scenario

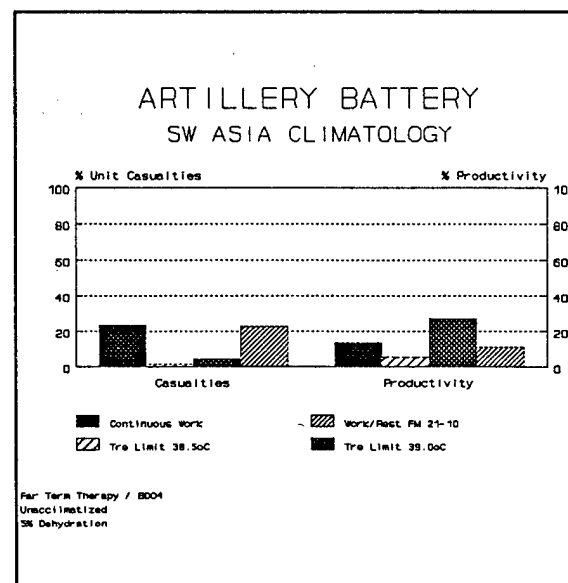


Figure 24. Unit Casualties and Productivity, Far Term Therapy/BDO4, Worst Case Scenario

Figures 25 through 32 show unit effectiveness as a function of the work discipline considered for each of the medical interventions modeled.

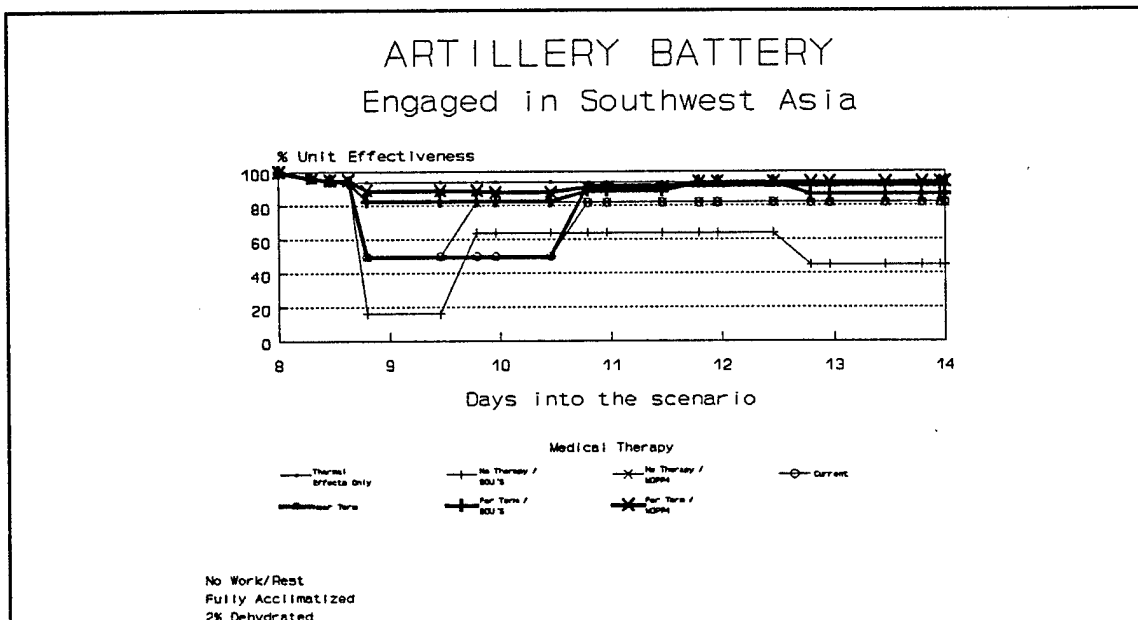


Figure 25. Artillery Unit Effectiveness, Continuous Work, Best Case Scenario

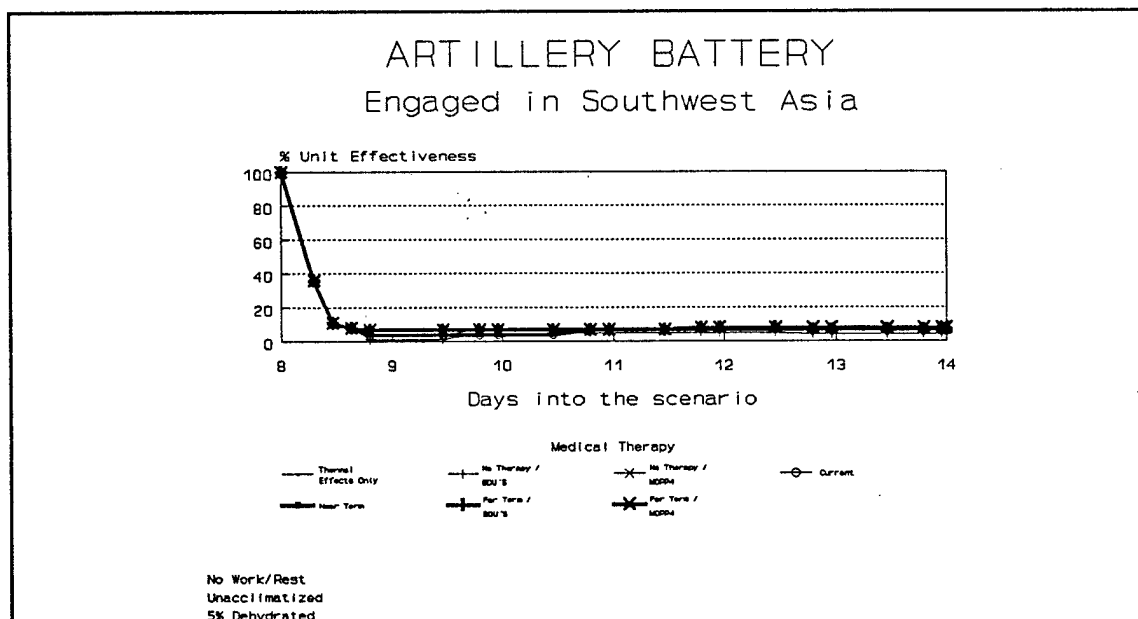


Figure 26. Artillery Unit Effectiveness, Continuous Work, Worst Case Scenario

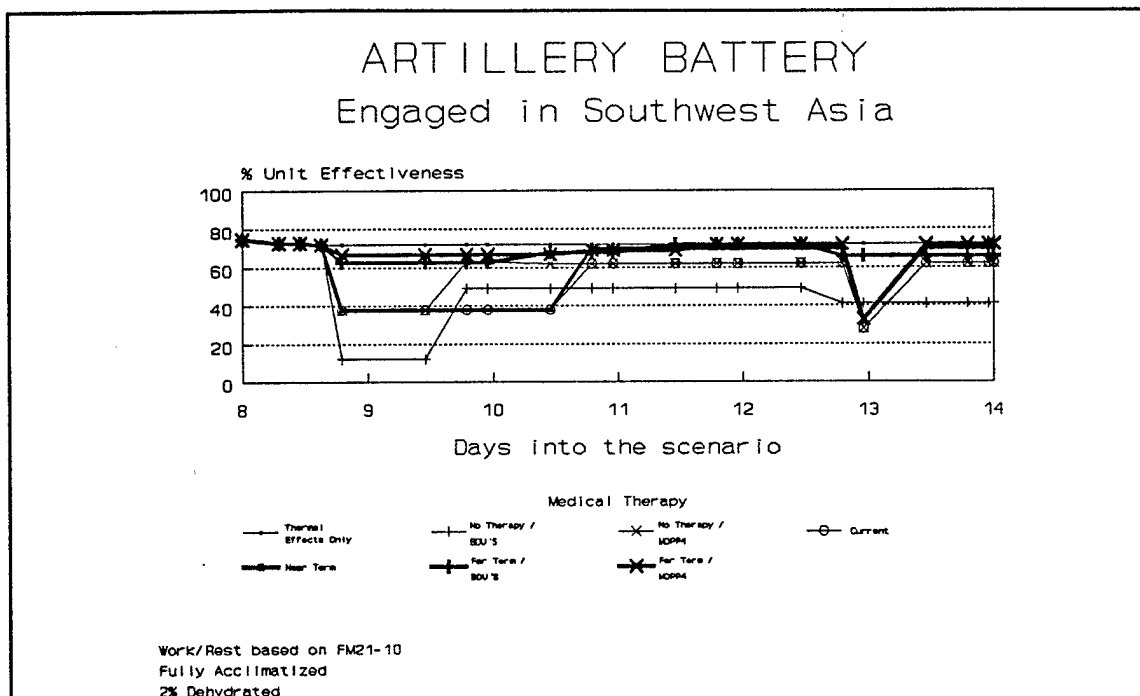


Figure 27. Artillery Unit Effectiveness, Work/Rest Discipline, Best Case Scenario

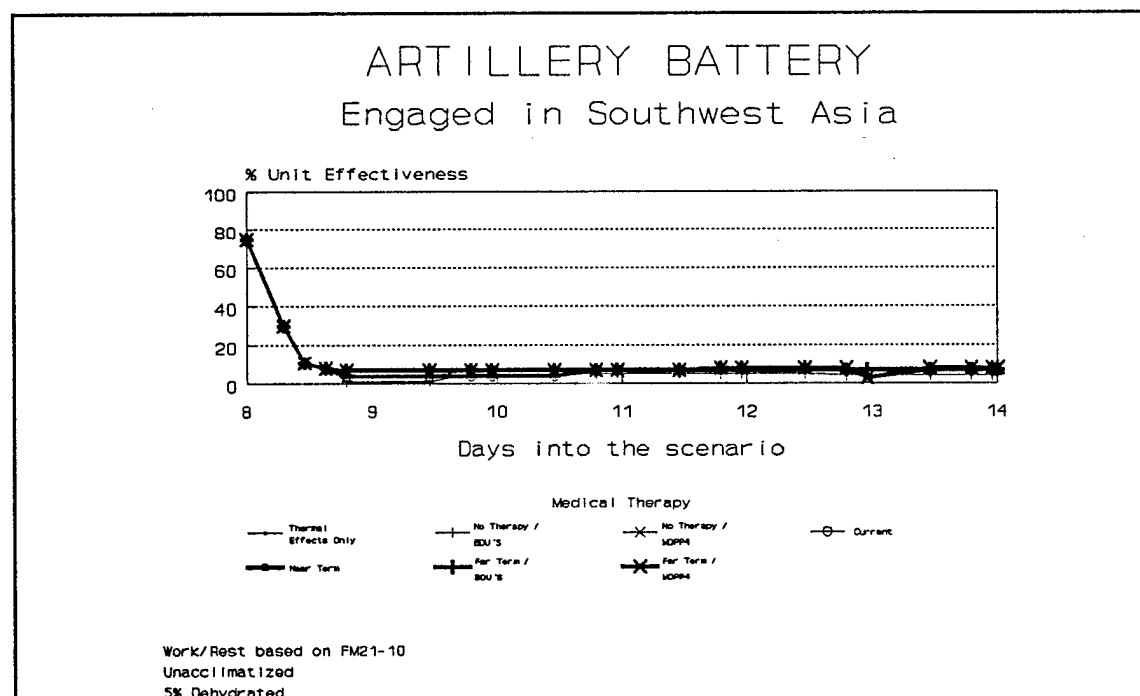


Figure 28. Artillery Unit Effectiveness, Work/Rest Discipline, Worst Case Scenario

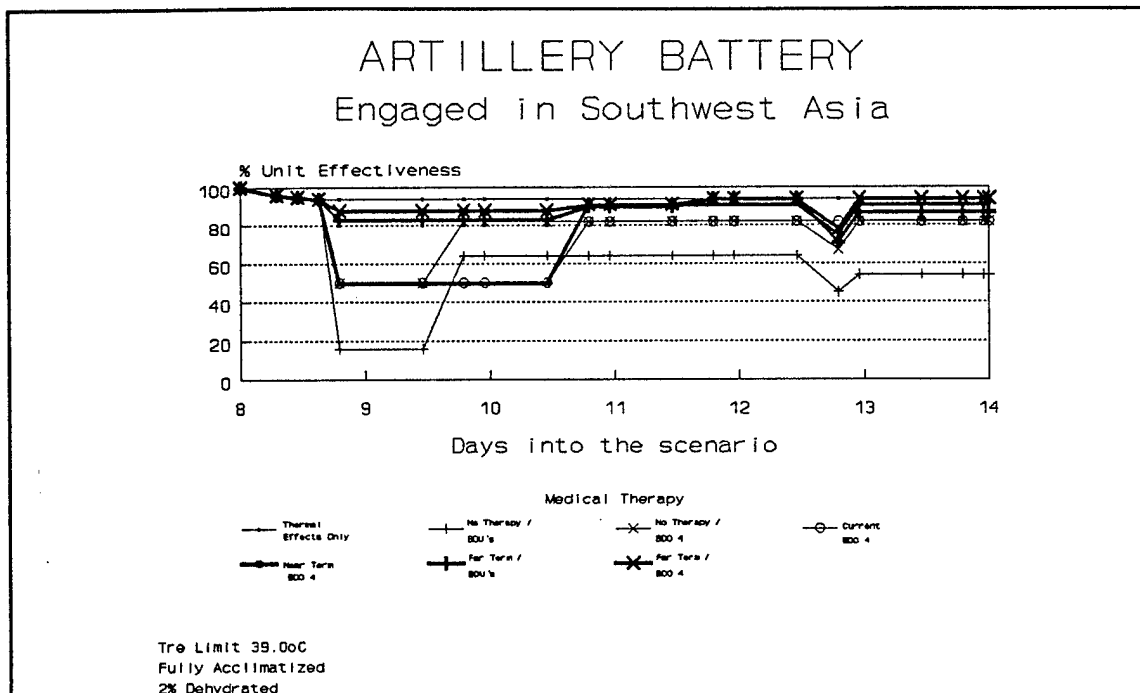


Figure 29. Artillery Unit Effectiveness, Tre Limit at 39°C, Best Case Scenario

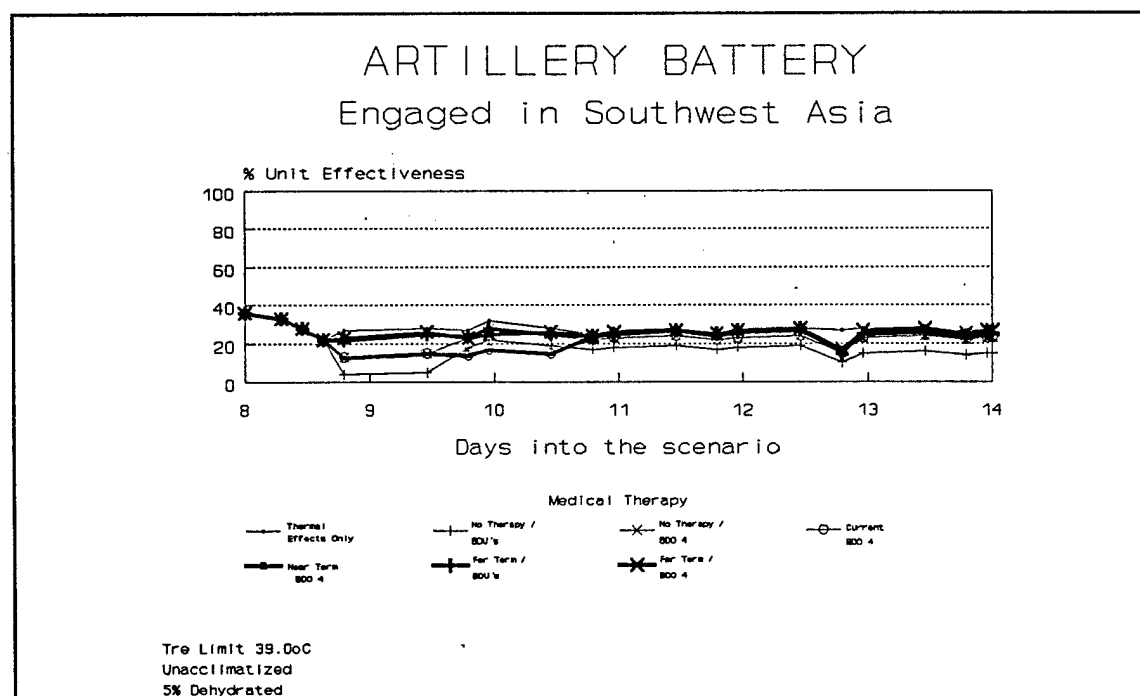


Figure 30. Artillery Unit Effectiveness, Tre Limit at 39°C, Worst Case Scenario

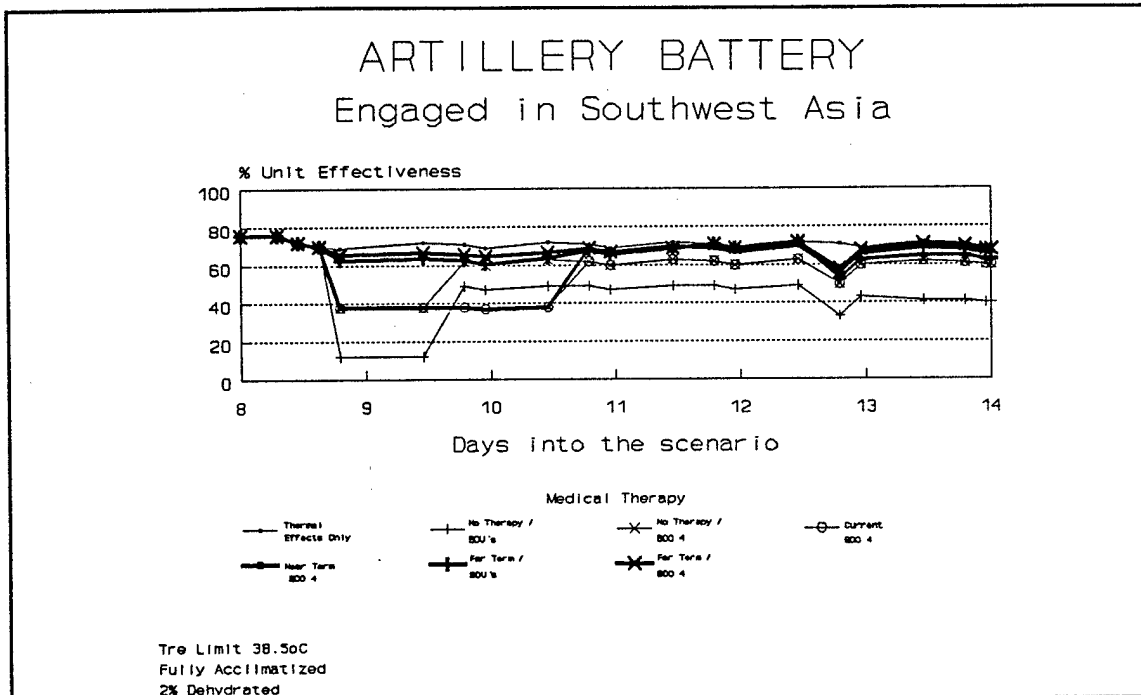


Figure 31. Artillery Unit Effectiveness, Tre Limit at 38.5°C, Best Case Scenario

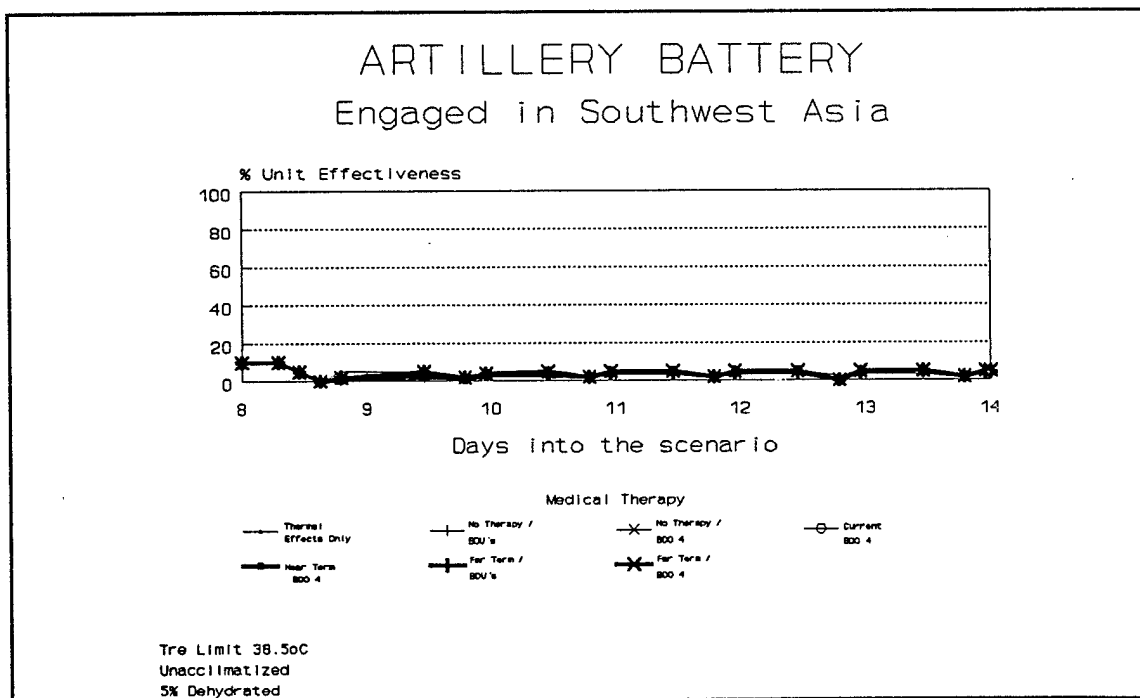


Figure 32. Artillery Unit Effectiveness, Tre Limit at 38.5°C, Worst Case Scenario

7.3 BDUs vs. MOPPI

During the course of the analysis, several questions arose as to how great an impact would be seen if MOPPI (overgarment only) were worn throughout the day. The results previously presented here in this report examined the use of BDUs in the field. A set of AURA runs were subsequently completed to examine the impact of wearing MOPPI throughout the scenario, only changing to BDU4 if necessary. The results of these runs are presented as Figures 33 through 46 and are grouped in threes as explained above.

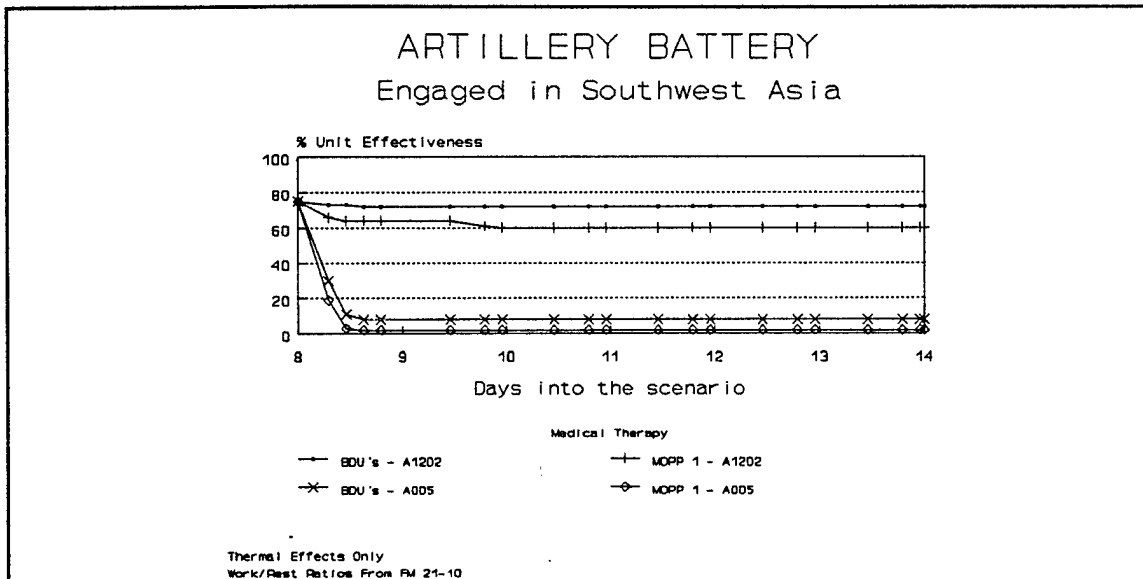


Figure 33. Artillery Unit Effectiveness, BDUs vs. MOPP1, Thermal Effects Only

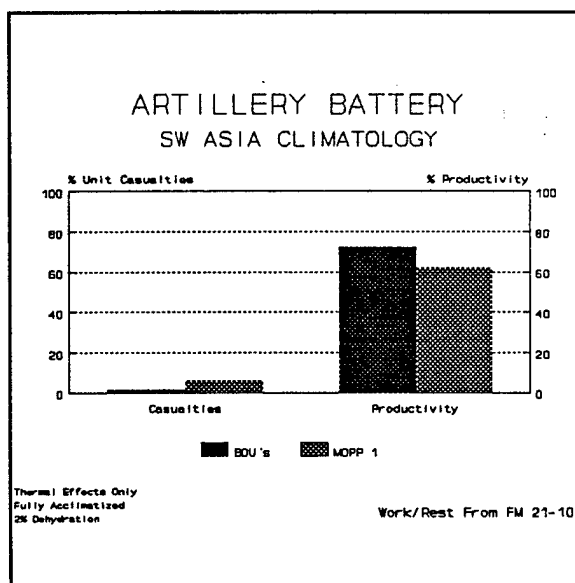


Figure 34. Unit Casualties and Productivity, BDUs vs. MOPP1, Thermal Effects Only, Best Case Scenario

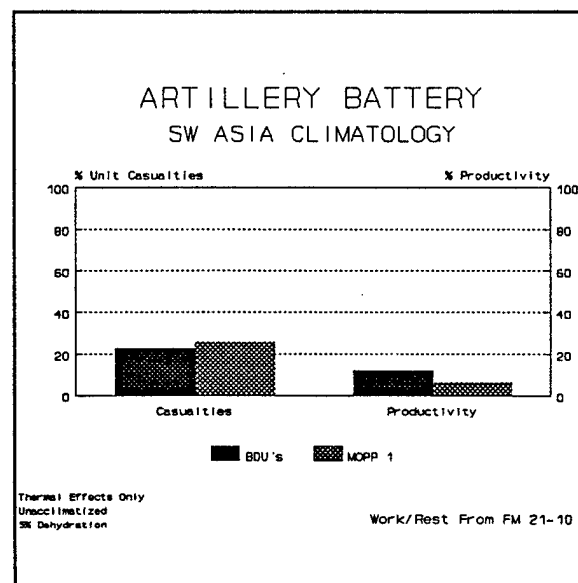


Figure 35. Unit Casualties and Productivity, BDUs vs. MOPP1, Thermal Effects Only, Worst Case Scenario

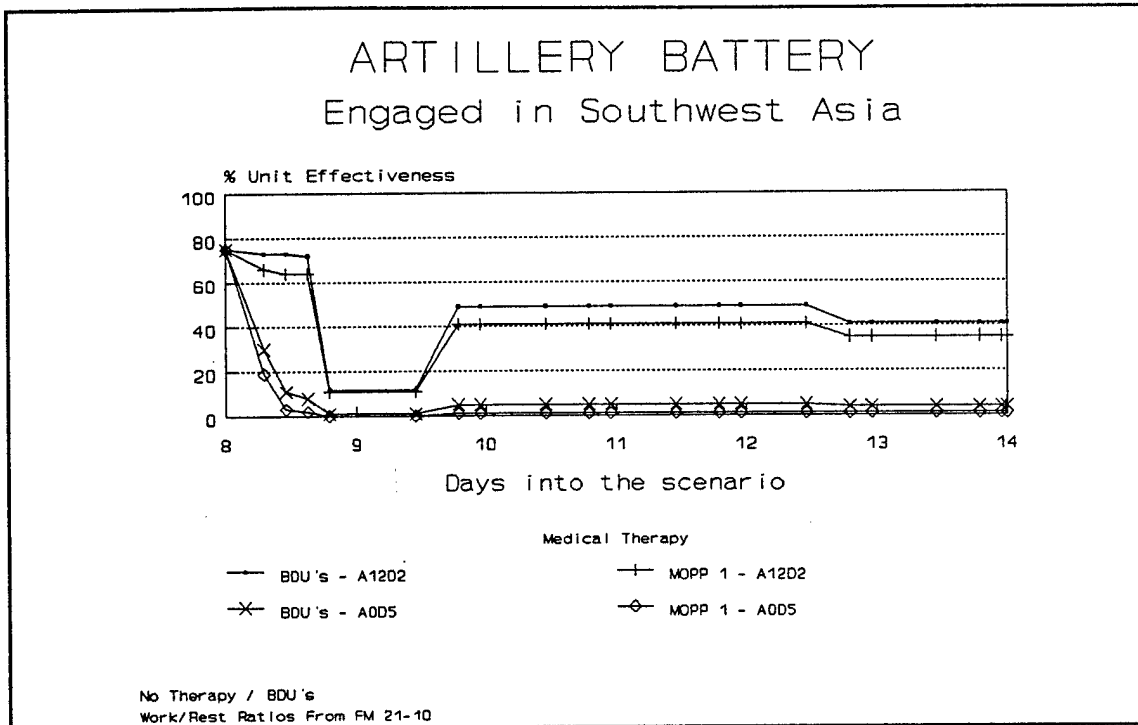


Figure 36. Artillery Unit Effectiveness, BDUs vs. MOPP1, No Therapy/BDUs (or MOPP1)

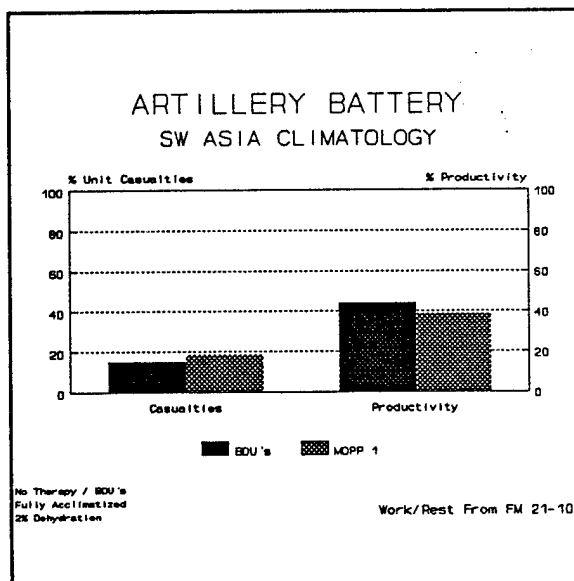


Figure 37. Unit Casualties and Productivity, BDUs vs. MOPP1, No Therapy/BDUs (or MOPP1), Best Case Scenario

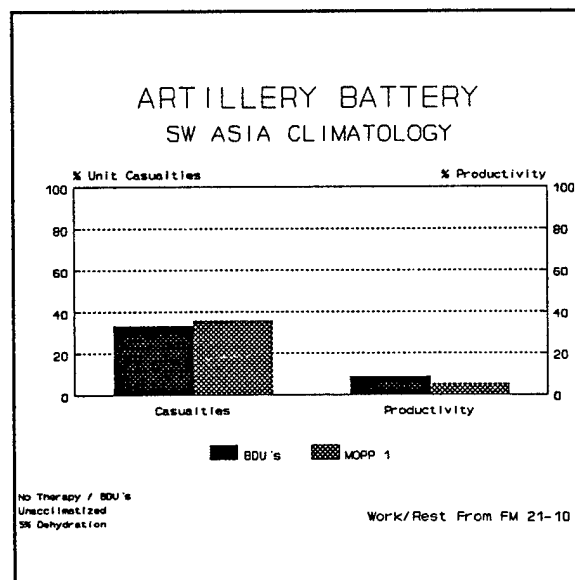


Figure 38. Unit Casualties and Productivity, BDUs vs. MOPP1, No Therapy/BDUs (or MOPP1), Worst Case Scenario

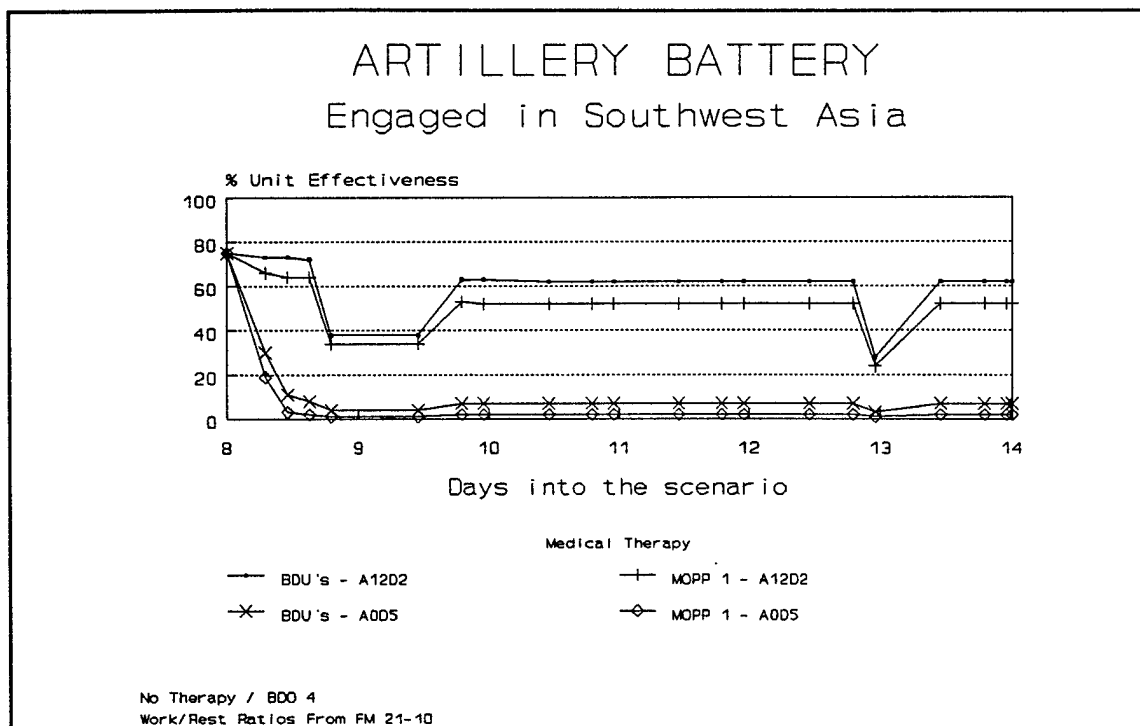


Figure 39. Artillery Unit Effectiveness, BDUs vs. MOPP1, No Therapy/BD04

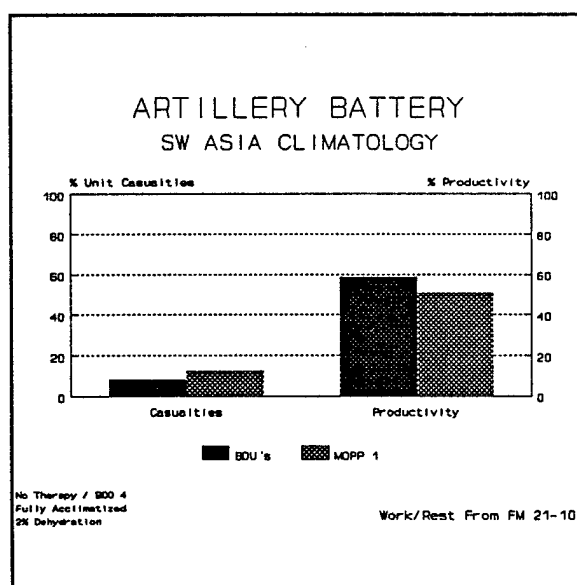


Figure 40. Unit Casualties and Productivity, BDUs vs. MOPP1, No Therapy/BD04, Best Case Scenario

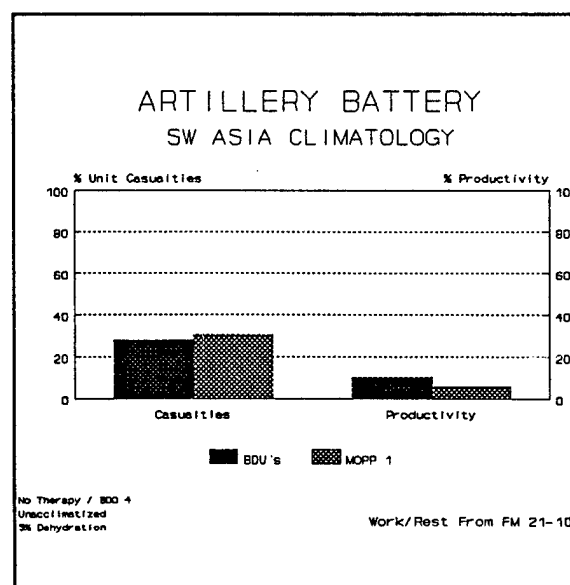


Figure 41. Unit Casualties and Productivity, BDUs vs. MOPP1, No Therapy/BD04, Worst Case Scenario

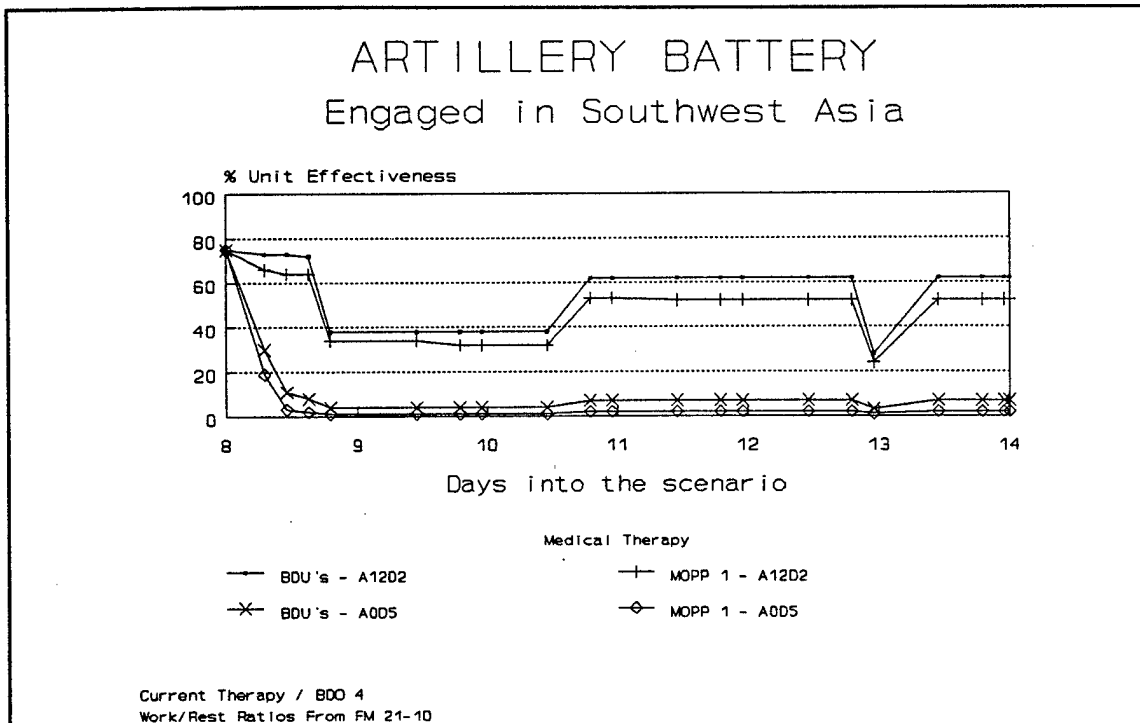


Figure 42. Artillery Unit Effectiveness, BDUs vs. MOPP1, Current Therapy

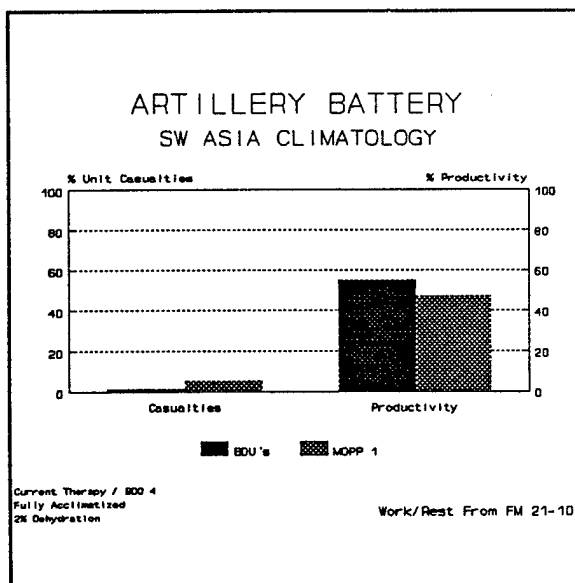


Figure 43. Unit Casualties and Productivity, BDUs vs. MOPP1, Current Therapy, Best Case Scenario

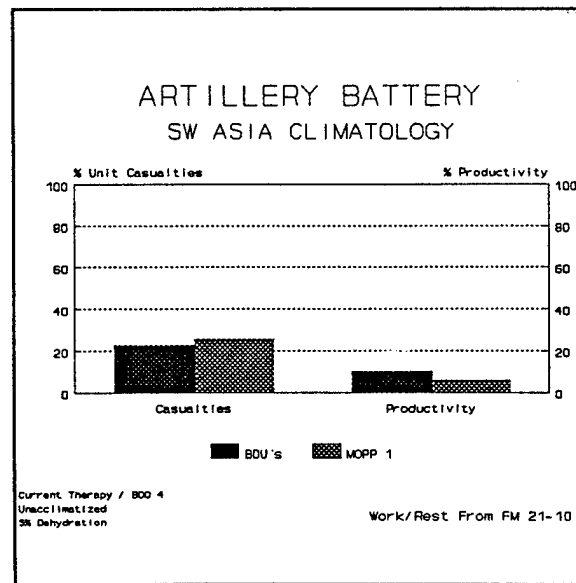


Figure 44. Unit Casualties and Productivity, BDUs vs. MOPP1, Current Therapy, Worst Case Scenario

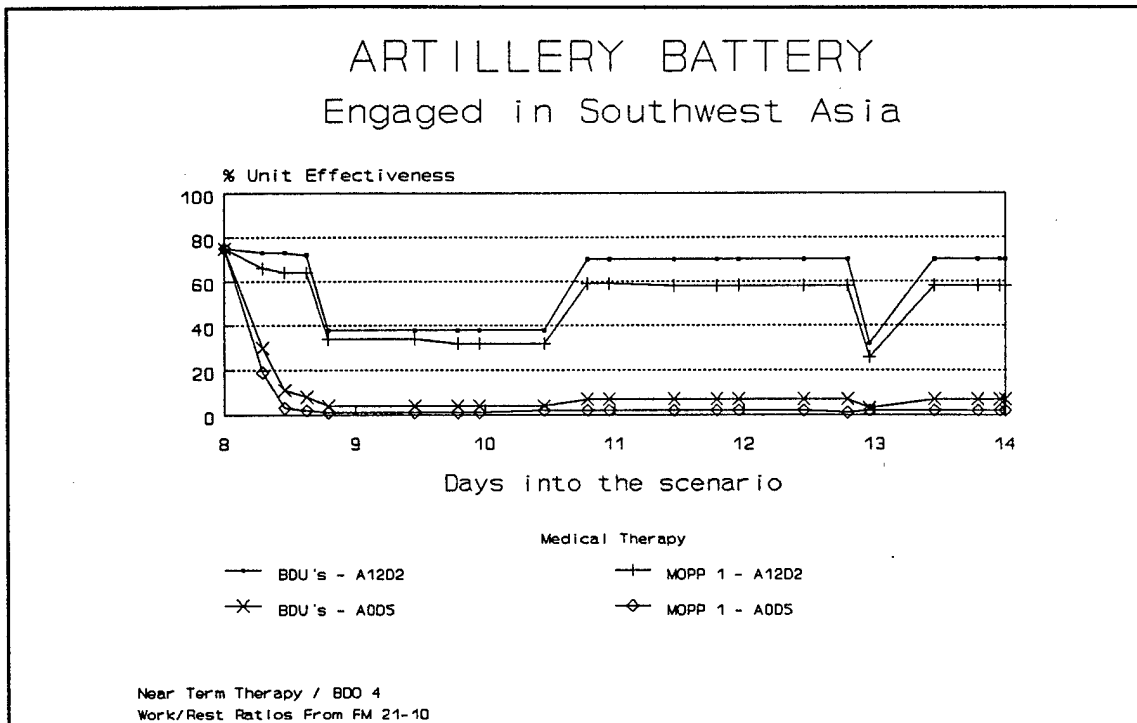


Figure 45. Artillery Unit Effectiveness, BDUs vs. MOPP1, Near Term Therapy

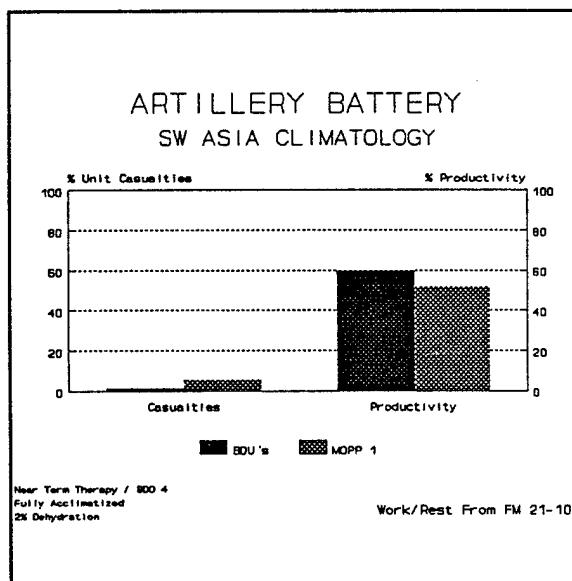


Figure 46. Unit Casualties and Productivity, BDUs vs. MOPP1, Near Term Therapy, Best Case Scenario

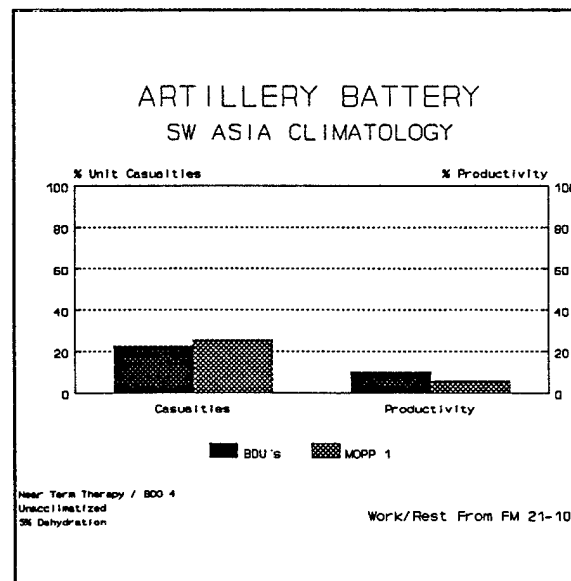


Figure 47. Unit Casualties and Productivity, BDUs vs. MOPP1, Near Term Therapy, Worst Case Scenario

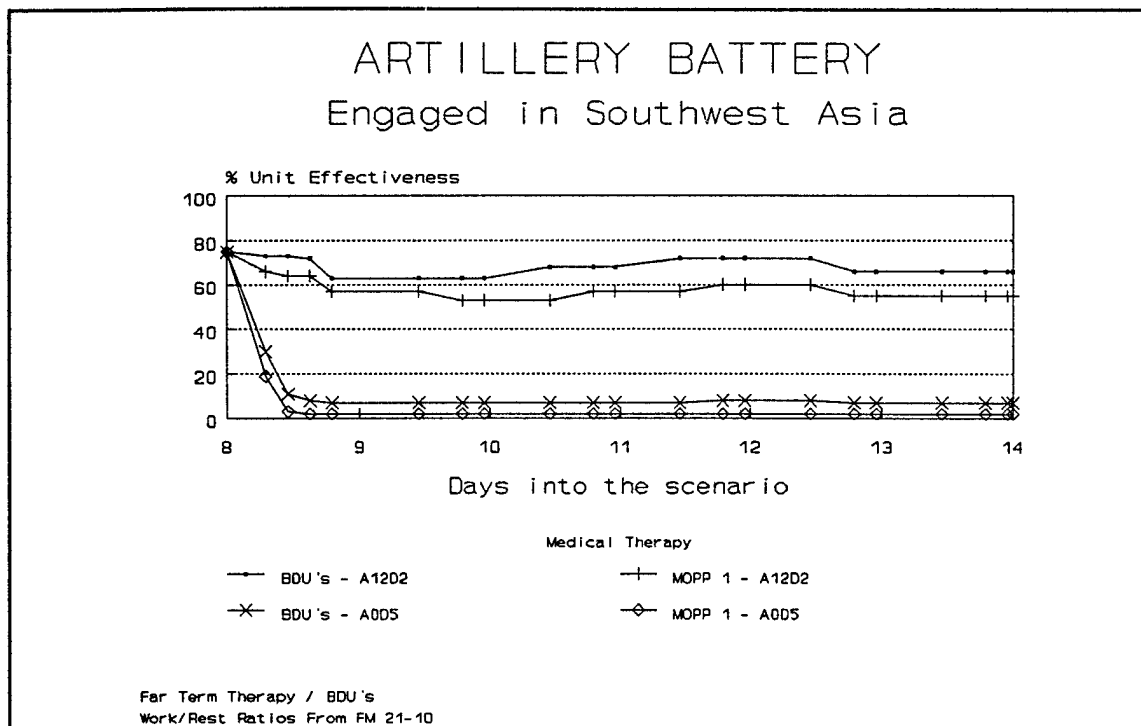


Figure 48. Artillery Unit Effectiveness, BDUs vs. MOPP1, Far Term Therapy/BDUs (or MOPP1)

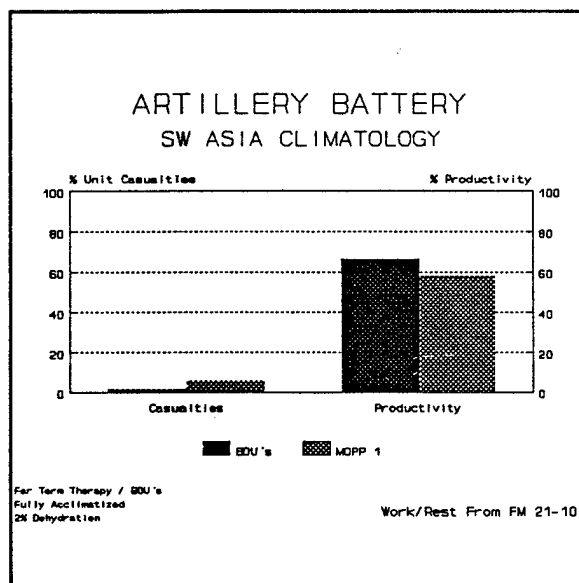


Figure 49. Unit Casualties and Productivity, BDUs vs. MOPP1, Far Term Therapy/BDUs (or MOPP1), Best Case Scenario

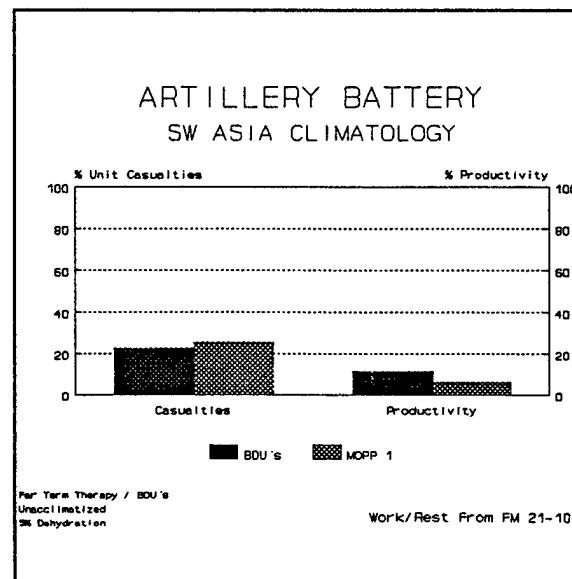


Figure 50. Unit Casualties and Productivity, BDUs vs. MOPP1, Far Term Therapy/BDUs (or MOPP1), Worst Case Scenario

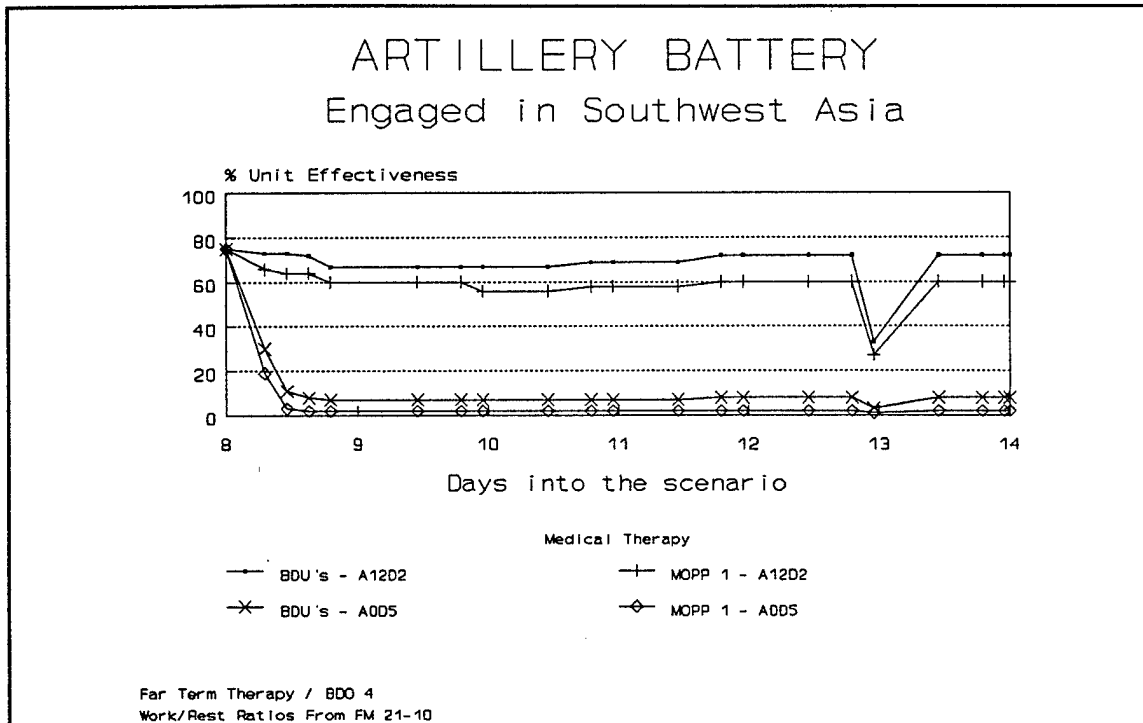


Figure 51. Artillery Unit Effectiveness, BDUs vs. MOPP1, Far Term Therapy/BDO4.

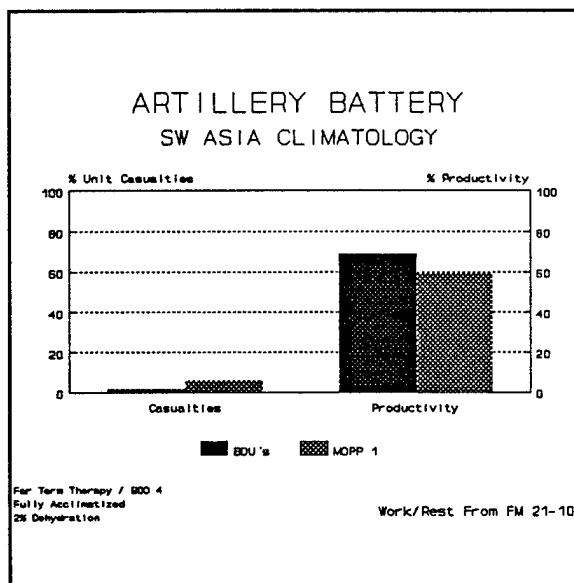


Figure 52. Unit Casualties and Productivity, BDUs vs. MOPP1, Far Term Therapy/BDO4, Best Case Scenario

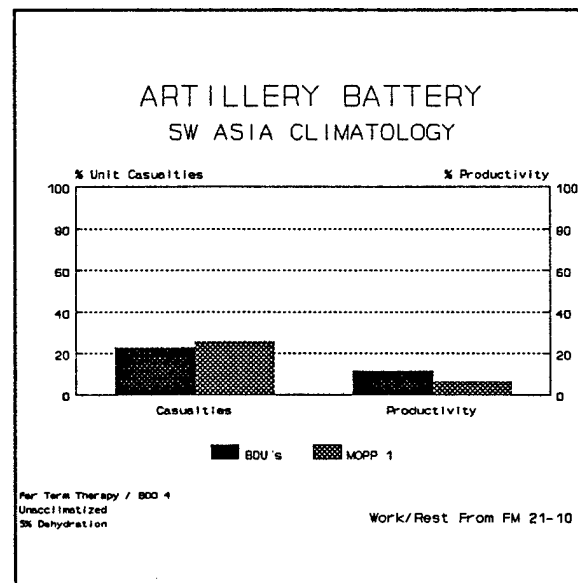


Figure 53. Unit Casualties and Productivity, BDUs vs. MOPP1, Far Term Therapy/BDO4, Worst Case Scenario

8. CONCLUSIONS

The unacclimatized/5% dehydrated cases precipitously drops unit effectiveness when compared with acclimatized/2% dehydrated soldiers. This effect was more dramatic than the chemical attacks, the medical intervention of the chemical attacks, or the implementation of doctrine for working in a hot environment. Even with minimal affects on casualties, the ability to productively operate was severely curtailed.

FM 21-10 often results in nearly the same casualty risk as using a no work/rest discipline.

Limiting work to achievable levels in the environment maintains productivity at high levels and may be used to effectively control the risk of casualty generation.

The chemical attack impact can be nearly as severe as the lack of acclimatization and high level of dehydration cases. Wearing protective equipment reduces chemical casualties and maintains unit effectiveness at higher levels than cases without protective equipment.

Adding the current therapy option to the use of protective equipment increases the duration of chemical incapacitation from one day to two days. Fatalities from chemical attack are prevented by the current therapy option for those attacks.

Use of the near-term therapy option results in a faster return of chemically-incapacitated soldiers.

Use of the far-term therapy option may reduce the impact of the nerve agent attack nearly completely for the attack portrayed without the use of protective equipment. The marginal chemical casualties, without protective equipment, caused less degradation in productivity and unit effectiveness than the decrement imposed by protective equipment.

No work/rest disciplines consistently provide the best unit effectiveness by maximizing productivity at the expense of thermal casualties. Use of 39°C limiting temperature provided nearly the same casualties and productivity as no work/rest discipline except during the extended wear of full protective equipment.

Use of a 38.5°C limiting temperature provided the lowest unit effectiveness and productivity by limiting thermal casualties. Use of work/rest cycles provided nearly the same casualties and productivity as the 38.5°C limiting temperature discipline except during the extended wear of full protective equipment.

Comparison between the wearing of BDU and MOPPI consistently showed that the BDU case had fewer casualties and higher productivity and unit effectiveness for every medical intervention, including the case where no chemical casualties were portrayed.

9. RECOMMENDATIONS

Commanders need to understand the consequences of utilizing unacclimatized or dehydrated personnel. In the SWA environment, these factors dominate good medical intervention for CW attacks as well as optimal thermal guidance. Current guidance should graphically support fact sheets and field manuals prepared for field use.

Sustaining operations in a CW environment will require development of a far-term capability. Current therapy options are effective in preserving life, but not in sustaining combat operations.

The current thermal disciplines, as represented in FM 21-10, results in high casualty risks at nearly the levels of using no discipline, while seriously degrading productivity and unit effectiveness. A new thermal discipline, perhaps similar to the approach identified as limiting temperature should be developed, tested, and fielded.

Development of tactical decision aids should be undertaken which can be used to balance the risk from chemical agent exposure and the risk of thermal strain in terms of casualties and mission requirements.

REFERENCES

1. Berlin, Henry M., Leander Stroschein and Ralph M. Goldman, A Computer Program to Predict Energy Cost, Rectal Temperature, and Heart Rate Response to Work, Clothing and Environment, Edgewood Arsenal Special Publication ED-SP-75011, Chemical Systems Laboratory, Aberdeen Proving Ground MD, November 1975.
2. McNally, Richard E., Stark, Maureen M., Ellzy, Diane T., Verification and Usage of the Goldman-Givoni Model: Predicting Core Temperature and Casualty Generation in Thermally Stressful Environments, Contract No. MDA903-88-D-1000, Science Applications International Corporation, Joppa MD, April 1990.
3. Matthew, W.T., Heat Stress Analysis, Heat Research Division, U.S. Army Research Institute of Environmental Medicine, Natick MA, February 1989.
4. McNally, Richard E., Ellzy, Diane T., Modular Chemical Assessment Structure Documentation, Contract No DAAA15-85-D-0007, Science Applications International Corporation, Joppa MD, November 1988.
5. Table of Organization and Equipment, TOE-06-367J.
6. Stark, Maureen M., Klopac, J. Terrence, Juarascio, Stephanie S., The Effects of Chemical Contamination/Decontamination of an M109A2 8-Gun Artillery Battery (U), Technical Report BRL-TR-2633, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground MD, February 1985, SECRET.
7. McNally, Richard E., Machovec, Alice M., Ellzy, Diane T., Evaluation of Sleep Discipline in Sustaining Unit Performance, Contract No MDA903-88-D-1000, Science Applications International Corporation, Joppa MD, October 1989.
8. Personal Communication from Mr. Leander Stroschein, USAREIM, June 1990.

APPENDIX A
Goldman-Givoni Source Listing

```

INTERFACE TO SUBROUTINE ATTIME
&      (TRET, TRBEG, DTREF, DTREFA, DELTM,
&      DELT, TDELAY, RISE, CPEFF, LAST,
&      TIM, VALUE, NEWMET, REST)
INTEGER DELT, LAST
REAL CPEFF, DELTM, DTREF, DTREFA, RISE, TDELAY, TIM,
&      TRBEG, TRET, VALUE
LOGICAL NEWMET, REST
DIMENSION VALUE(2,2048)
END
INTERFACE TO SUBROUTINE DIGIT
&      (MIDPT, LABEL, SCREEN, LINE, AXIS)
INTEGER MIDPT, LABEL, LINE
CHARACTER*1 SCREEN, AXIS
DIMENSION SCREEN(24,80)
END
INTERFACE TO SUBROUTINE DISPLA
&      (TEMPC, HUMID, WIND, METAB, WEX,
&      CLO, IMCLO, GAMMAC, GAMMAI, SKIN, DEHYD,
&      DIH, TIME, TREND, LIMIT)
REAL CLO, GAMMAC, GAMMAI, HUMID, IMCLO, METAB, SKIN, TEMPC,
&      WIND, DIH, DEHYD, TIME, TREND, WEX
LOGICAL LIMIT
END
INTERFACE TO FUNCTION ERFCTN(X)
REAL ERFCTN, X
END
INTERFACE TO SUBROUTINE INIT
&      (AREA, CLO, DEHYD, DIH, GAMMAC, GAMMAI,
&      HUMID, IMCLO, METAB, WEX, PATM, SKIN,
&      TEMPC, WIND, TREND)
REAL AREA, CLO, DEHYD, DIH, GAMMAC, GAMMAI, HUMID, IMCLO,
&      METAB, PATM, SKIN, TEMPC, TREND, WEX, WIND
END
INTERFACE TO FUNCTION LASTTM
&      (TMBEG, TRBEG, TREND, TDELAY, DTREFA, CPEFF)
INTEGER LASTTM, TMBEG
REAL CPEFF, DTREFA, TDELAY, TRBEG, TREND
END
INTERFACE TO SUBROUTINE MENU
&      (CHOICE, DONE, RUN)
CHARACTER*2 CHOICE
LOGICAL DONE, RUN
END
INTERFACE TO SUBROUTINE NEWMET
&      (METRAT, TREF, TREND,
&      FIRST, TOHIGH, TOLOW)
REAL METRAT, TREF, TREND
LOGICAL FIRST, TOHIGH, TOLOW
END
INTERFACE TO SUBROUTINE PRBCAS(TRE,PROB)
REAL PROB, TRE
END
INTERFACE TO SUBROUTINE PLOT
&      (VALUE, SCREEN, TMAX, TMIN,
&      COLMAX, COLMIN, ROWMAX, ROWMIN)
INTEGER ROWMAX, ROWMIN, COLMAX, COLMIN
REAL TMAX, TMIN, VALUE
CHARACTER*1 SCREEN
DIMENSION SCREEN(24,80), VALUE(2,2048)
END
INTERFACE TO SUBROUTINE RACTIV
&      (TEMPC, HUMID, WIND, METAB, WEX,
&      CLO, IMCLO, GAMMAC, GAMMAI, SKIN, DEHYD,

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&          DIH, TIME, TREND, EQUIL, DONE,
&          LIMIT)
  INTEGER EQUIL
  REAL CLO, GAMMAC, GAMMAI, HUMID, IMCLO, METAB, SKIN,
&    TEMPC, WIND, DIH, DEHYD, TIME, TREND, WEX
  LOGICAL DONE, LIMIT

  DIMENSION TEMPC(128), HUMID(128), WIND(128), METAB(128),
&    WEX(128), CLO(128), IMCLO(128), GAMMAC(128),
&    GAMMAI(128),
&    SKIN(128), DEHYD(128), DIH(128), TIME(128)
  END
  INTERFACE TO SUBROUTINE RECOV
&    (TRET, TREO, DTREF, TIME, DELAY, RISE,
&    DELT, CPEFF)
  INTEGER DELT
  REAL CPEFF, DELAY, DTREF, RISE,
&    TREO, TRET, TIME
  END
  INTERFACE TO SUBROUTINE RESULT (VALUE)
  REAL VALUE
  DIMENSION VALUE(2,2048)
  END
  INTERFACE TO SUBROUTINE SAVE
&    (VALUE, SCREEN, CASUAL, MAXTRE, N)
  INTEGER N
  REAL CASUAL, MAXTRE, VALUE
  CHARACTER*1 SCREEN
  DIMENSION SCREEN(24,80), VALUE(2,2048)
  END
  INTERFACE TO SUBROUTINE SCALER (TIM,SCALE)
  REAL TIM, SCALE
  END
  INTERFACE TO SUBROUTINE SET
&    (SCREEN, COLMIN, COLMAX, ROWMIN, ROWMAX, TMAX, TMIN)
  INTEGER COLMIN, COLMAX, ROWMIN, ROWMAX
  REAL TMAX, TMIN
  CHARACTER*1 SCREEN
  DIMENSION SCREEN(24,80)
  END
  INTERFACE TO SUBROUTINE SHOW (SCREEN)
  CHARACTER*1 SCREEN
  DIMENSION SCREEN(24,80)
  END
  INTERFACE TO SUBROUTINE TCORE
&    (AREA, CLO, DEHYD, DIH, PATM,
&    GAMMAC, GAMMAI, HUMID, IMCLO,
&    METAB, WEX, SKIN, TEMPC, WIND,
&    TREF, TAU, TLAG, PCAS, DTREFA, M,
&    EDIF)
  REAL AREA, CLO, DEHYD, DIH, DTREFA,
&    EDIF, GAMMAC, GAMMAI, HUMID,
&    IMCLO, M,
&    METAB, PATM, SKIN, TAU, PCAS, TLAG,
&    TEMPC, TREF, WEX, WIND
  END
  INTERFACE TO SUBROUTINE TRETIM
&    (VALUE, TIME, TREF, DTREFA, M, EDIF,
&    EQUIL, LIMIT)
  INTEGER EQUIL
  REAL M, EDIF, DTREFA, TIME,
&    TREF, VALUE
  LOGICAL LIMIT
  DIMENSION VALUE(2,2048)

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DIMENSION DTREFA(128), M(128), TIME(128), TREF(128),
&          EDIF(128)
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INTERFACE TO SUBROUTINE WORK
&          (TRET, TREO, DTREF, DTREFA, TIME, DELAY,
&          RISE, DELT, NEWMET)
INTEGER DELT
REAL DTREF, DTREFA, DELAY,
&      TREO, TRET, TIME
LOGICAL NEWMET
END
INTERFACE TO SUBROUTINE XAXIS
&          (SCREEN, COLMIN, COLMAX, ROWMAX, SCALE)
INTEGER COLMAX, COLMIN, ROWMAX
REAL SCALE
CHARACTER*1 SCREEN
DIMENSION SCREEN(24,80)
END
INTERFACE TO SUBROUTINE YAXIS
&          (SCREEN, ROWMIN, ROWMAX, COLMIN, TMIN, TMAX)
INTEGER ROWMIN, ROWMAX, COLMIN
REAL TMIN, TMAX
CHARACTER*1 SCREEN
DIMENSION SCREEN(24,80)
END
C ** PROGRAM **
PROGRAM GOLDMAN
C*****
C THE GOLDMAN-GIVONI MODEL HAS EVOLVED OVER A NUMBER OF
C YEARS BASED ON EMPIRICAL EQUATIONS DEVELOPED AT THE
C U.S. ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE
C*****
REAL AREA, CLO, DEHYD, DIH, DTREFA, EDIF, GAMMAC, GAMMAI,
&      HUMID, IMCLO, M, METAB, PATM, PCAS, SKIN, TAU,
&      TEMPC, TIME, TLAG, TREF, TREND, VALUE, WEX, WIND
INTEGER EQUIL, T
CHARACTER PMODE*1
LOGICAL DONE, FIRST, LIMIT, TOHIGH, TOLOW

DIMENSION VALUE(2,2048)
DIMENSION AREA(128), CLO(128), DEHYD(128), DIH(128),
&      DTREFA(128), EDIF(128), GAMMAC(128), GAMMAI(128),
&      HUMID(128), IMCLO(128),
&      M(128), METAB(128), PATM(128),
&      SKIN(128), TEMPC(128), TIME(128),
&      TREF(128), WEX(128), WIND(128)

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DONE=.FALSE.
LIMIT=.FALSE.

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&      GAMMAI(1), HUMID(1), IMCLO(1), METAB(1),
&      WEX(1), PATM(1), SKIN(1), TEMPC(1), WIND(1),
&      TREND)

DISPLAY TCORE MENU OR BEGIN BATCH PROCESSING ROUTINES
10 WRITE(6,FMT='(1X,A25,A39)')
&      'RUN TCORE (I)NTERACTIVELY',
&      ' OR TO ESTABLISH METABOLIC RATE (L)IMIT'
READ(5,FMT='(A1)',ERR=10) PMODE

```

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C
IF ((PMODE .EQ. 'I') .OR. (PMODE .EQ. 'i')) THEN
  CONTINUE
ELSE IF ((PMODE .EQ. 'L') .OR. (PMODE .EQ. 'l')) THEN
  LIMIT=.TRUE.
ELSE
  GOTO 10
ENDIF

C
100 CONTINUE
FIRST=.TRUE.

C
CALL RACTIV(TEMPC, HUMID, WIND, METAB, WEX,
&          CLO, IMCLO, GAMMAC, GAMMAI, SKIN, DEHYD,
&          DIH, TIME, TREND, EQUIL, DONE,
&          LIMIT)

C
IF (DONE) GOTO 5000

C
START CALCULATIONS

C
CR      WRITE(6,*) '    EQUIL',EQUIL
CR
CR
C
DO 1000 T=1,EQUIL
C
500 CONTINUE

C
CALL TCORE(AREA(1), CLO(T), DEHYD(T), DIH(T), PATM(1),
&          GAMMAC(T), GAMMAI(T), HUMID(T), IMCLO(T),
&          METAB(T), WEX(T), SKIN(T), TEMPC(T), WIND(T),
&          TREF(T), TAU, TLAG, PCAS, DTREFA(T), M(T),
&          EDIF(T))

C
IF (LIMIT) THEN
  IF (ABS(TREF(T)-TREND) .LE. 0.0005) THEN
    WRITE(6,FMT='(1X,A34,A21,F6.2,A4,F6.0,A6)')
    &      'THE METABOLIC RATE WHICH PRODUCES ',
    &      'A FINAL CORE TEMP OF ',TREF(T),
    &      ' IS ',METAB(T),' WATTS'
  ELSE
    CALL NEWMET(METAB(T), TREF(T), TREND,
    &          FIRST, TOHIGH, TOLOW)
    IF (TOHIGH .OR. TOLOW) THEN
      GOTO 100
    ELSE
      GOTO 500
    ENDIF
  ENDIF
ENDIF
ENDIF

C
CR      WRITE(6,*) ' ',T,' TIME ',TIME(T),' THE VALUE OF TREF'
CR      WRITE(6,*) ' WAS ',TREF(T)
CR
1000 CONTINUE

C
COMPUTE TIME DEPENDENT CORE TEMPERATURE

C
CALL TRETIM (VALUE, TIME, TREF, DTREFA, M, EDIF,
&          EQUIL, LIMIT)
C

```


GRAPHICALLY DISPLAY THE INTERACTIVE RESULTS
OR
GENERATE THE OUTPUT FILE

CALL RESULT (VALUE)

IF (.NOT. DONE) GOTO 100

5000 CONTINUE

STOP

END

***SUBROUTINES & FUNCTIONS LISTED IN ALPHAPETICAL ORDER ***

A

SUBROUTINE ATTIME (TRET, TRBEG, DTREF, DTREFA, DELTM,
& DELT, TDELAY, RISE, CPEFF, LAST,
& TIM, VALUE, NEWMET, REST)
INTEGER DELT, LAST
REAL CPEFF, DELTM, DTREF, DTREFA, RISE, TDELAY, TIM,
& TRBEG, TRET, VALUE
LOGICAL NEWMET, REST.

DIMENSION VALUE(2,2048)

Use the recovery equations ONLY for resting personnel,
the work equations apply to all working periods--
with the time delay for working periods proportional
to the change in work levels only.

(Conversation with Mr. Leander Stroschein on 27 April
1990.)

IF (.NOT. REST) THEN

CALL WORK (TRET, TRBEG, DTREF, DTREFA, DELTM, TDELAY,
& RISE, DELT, NEWMET)

ELSE

CALL RECOV (TRET, TRBEG, DTREF, DELTM, TDELAY, RISE,
& DELT, CPEFF)

ENDIF

LAST=LAST+1

VALUE(1, LAST)=TIM

VALUE(2, LAST)=TRET

RETURN

END

D

SUBROUTINE DIGIT(MIDPT, LABEL, SCREEN, LINE, AXIS)
INTEGER MIDPT, LABEL, LINE
CHARACTER*1 SCREEN, STRING, AXIS

DIMENSION SCREEN(24,80), STRING(4)

IF (LINE+1 .GT. 24 .OR. LINE+1 .LT. 1 .OR.
& MIDPT .GT. 80 .OR. MIDPT-3 .LT. 1) THEN
WRITE(6, FMT='(1X, A8, I4, A15, I4, A32)')
& 'THE ROW ', LINE, ' OR THE COLUMN ', MIDPT,
& ' EXCEEDED THE ESTABLISHED LIMITS'
WRITE(6, FMT='(1X)')
RETURN

ENDIF

IF (AXIS .EQ. 'X') THEN
IF (LABEL .LT. 10) THEN

```

SCREEN(LINE+1,MIDPT)=CHAR(LABEL+48)
ELSE IF (LABEL .LT. 100) THEN
SCREEN(LINE+1,MIDPT-1)=CHAR(LABEL/10+48)
SCREEN(LINE+1,MIDPT)=CHAR(MOD(LABEL,10)+48)
ELSE IF (LABEL .LT. 1000 .AND. MIDPT .LT. 79) THEN
SCREEN(LINE+1,MIDPT-1)=CHAR(LABEL/100+48)
SCREEN(LINE+1,MIDPT)=CHAR(MOD(LABEL,100)/10+48)
SCREEN(LINE+1,MIDPT+1)=CHAR(MOD(LABEL,10)+48)
ELSE IF (LABEL .LT. 1000 .AND. MIDPT .EQ. 79) THEN
SCREEN(LINE+1,MIDPT-2)=CHAR(LABEL/100+48)
SCREEN(LINE+1,MIDPT-1)=CHAR(MOD(LABEL,100)/10+48)
SCREEN(LINE+1,MIDPT)=CHAR(MOD(LABEL,10)+48)
ELSE IF (LABEL .LT. 10000 .AND. MIDPT .LT. 79) THEN
SCREEN(LINE+1,MIDPT-2)=CHAR(LABEL/1000+48)
SCREEN(LINE+1,MIDPT-1)=CHAR(MOD(LABEL,1000)/100+48)
SCREEN(LINE+1,MIDPT)=CHAR(MOD(LABEL,100)/10+48)
SCREEN(LINE+1,MIDPT+1)=CHAR(MOD(LABEL,10)+48)
ELSE IF (LABEL .LT. 10000 .AND. MIDPT .EQ. 79) THEN
SCREEN(LINE+1,MIDPT-3)=CHAR(LABEL/1000+48)
SCREEN(LINE+1,MIDPT-2)=CHAR(MOD(LABEL,1000)/100+48)
SCREEN(LINE+1,MIDPT-1)=CHAR(MOD(LABEL,100)/10+48)
SCREEN(LINE+1,MIDPT)=CHAR(MOD(LABEL,10)+48)
ENDIF
ELSE IF (AXIS .EQ. 'Y') THEN
IF (LABEL .LT. 10) THEN
SCREEN(LINE,MIDPT-2)=CHAR(LABEL+48)
ELSE IF (LABEL .LT. 100) THEN
SCREEN(LINE,MIDPT-3)=CHAR(LABEL/10+48)
SCREEN(LINE,MIDPT-2)=CHAR(MOD(LABEL,10)+48)
ENDIF
ENDIF
ENDIF

RETURN
END
C ** D **
SUBROUTINE DISPLA(TEMPC, HUMID, WIND, METAB, WEX,
& CLO, IMCLO, GAMMAC, GAMMAI, SKIN, DEHYD,
& DIH, TIME, TREND, LIMIT)
REAL CLO, GAMMAC, GAMMAI, HUMID, IMCLO, METAB, SKIN, TEMPC,
& WIND, DIH, DEHYD, TIME, TREND, WEX
LOGICAL LIMIT

WRITE(6,FMT='(15X,A7,2X,I5,2X,A7)')
& 'AT TIME',INT(TIME),'minutes'
WRITE(6,FMT='(1X,A50)')
& '*****'
WRITE(6,FMT='(1X, A34, F6.1, A11)')
& ' 1 Temperature',TEMPC,
& ' degrees C '
WRITE(6,FMT='(1X, A34, F6.1, A2)')
& ' 2 Relative Humidity',HUMID,' %'
WRITE(6,FMT='(1X, A34, F6.1, A6)')
& ' 3 Wind Speed',WIND,' m/sec'
WRITE(6,FMT='(1X, A34, F6.0, A6)')
& ' 4 Metabolic Work Rate',METAB,' Watts'
WRITE(6,FMT='(1X, A34, F6.0, A6)')
& ' 5 External Work Completed',WEX,' Watts'
WRITE(6,FMT='(1X, A34, F6.2, A5)')
& ' 6 Clothing Insulation',CLO,' Clo '
WRITE(6,FMT='(1X, A34, F6.2)')
& ' 7 Im/Clo effective permeability',IMCLO
WRITE(6,FMT='(1X, A34, F6.2)')
& ' 8 Gamma wind correction (CLO)',GAMMAC
WRITE(6,FMT='(1X, A34, F6.2)')

```

```

&      ' 9 Gamma wind correction (Im/CLO)', GAMMAI
WRITE(6,FMT='(1X, A34, F6.1, A11)')
&      ' 10 Skin Temperature      ', SKIN,
&      ' degrees C'
WRITE(6,FMT='(1X,A34,F6.1)')
&      ' 11 Days in Heat          ', DIH
WRITE(6,FMT='(1X,A34,F6.1,A2)')
&      ' 12 Dehydration           ', DEHYD, ' %'
IF (LIMIT)
&WRITE(6,FMT='(1X,A34,F6.2,A3)')
&      ' 20 Core Temperature Limit  ', TREND, ' oC'
WRITE(6,FMT='(1X,A50)')
&      '*****'
WRITE(6,FMT='(1X)')

```

```

RETURN
END

```

C **E**

FUNCTION ERFCTN(X)

C*****

C Computes the value of the error function at the point X

C Ref: C. Hastings, Approximations for Digital Computers,

C Princeton Univ. Press, Princeton, NJ, 1955

C Referenced by: CALC

C External References: None

C*****

```

REAL A1, A2, A3, A4, A5, A6, ERFCTN, PI, SIGN, X, X2, X3,
&      X4, X5, X6, XMAX, XMIN, Y

```

```

PARAMETER (A1=0.0705230784, A2=0.0422820123, A3=0.0092705272,
&      A4=0.0001520143, A5=0.0002765672, A6=0.0000430638,

```

```

&      PI=3.14159265, XMIN=1.E-5, XMAX=5.)

```

```

X IS EQUAL TO THE Z-SCORE OF A CUMULATIVE NORMAL DISTRIBUTION
* 1/ SQRT(2)      (X = Z * 1/SQRT(2))

```

```

IF (X .EQ. 0.) THEN
  ERFCTN=0.0
  GO TO 999

```

END IF

```

SIGN=X/ABS(X)
X=ABS(X)

```

```

IF (X .LT. XMIN) THEN
  ERFCTN=2.*X/SQRT(PI)
ELSE IF (X .GT. XMAX) THEN
  ERFCTN=1.0

```

```

ELSE
  X2=X*X
  X3=X2*X
  X4=X3*X
  X5=X4*X
  X6=X5*X

```

```

Y=1.+A1*X
Y=Y+A2*X2
Y=Y+A3*X3
Y=Y+A4*X4
Y=Y+A5*X5
Y=Y+A6*X6

```

Y=Y**16

```

C      Y=1./Y
      ERFCTN=1.-Y
      END IF
C
C      X=SIGN*X
      ERFCTN=SIGN*ERFCTN
C
C      TO GENERATE PROBABILITY ON CUMULATIVE NORMAL DISTRIBUTION
      RETURN ERF/2 + 0.5
C
      ERFCTN = ERFCTN/2.0 + 0.5
      ERFCTN = ERFCTN * 100.0
C
999 RETURN
      END
C **I**
      SUBROUTINE INIT(AREA, CLO, DEHYD, DIH, GAMMAC, GAMMAI,
&                     HUMID, IMCLO, METAB, WEX, PATM, SKIN,
&                     TEMPC, WIND, TREND)
C*****
C      Subroutine init initializes the variables used by
C      TCORE to their appropriate defaults
C      Referenced by: Main program
C      External References: None
C*****
      REAL AREA, CLO, DEHYD, DIH, GAMMAC, GAMMAI, HUMID, IMCLO,
&      METAB, PATM, SKIN, TEMPC, TREND, WEX, WIND
C
C      SET DEFAULTS FOR TCORE VARIABLES
C
      SKIN = 36.5
      AREA = 1.8
      WIND = 3.
      GAMMAC = 0.26
      GAMMAI = 0.38
      TEMPC=20
      METAB=425.
      WEX=0.
      HUMID=20
      CLO=1.13
      IMCLO=.43
      PATM=760.
      DIH = 12.
      DEHYD = 0.
      TREND = 38.5
C
      RETURN
      END
C ** I **
      SUBROUTINE INPUT(TEMPC, HUMID, WIND, METAB, WEX,
&                     CLO, IMCLO, GAMMAC, GAMMAI, SKIN, DEHYD,
&                     DIH, TREND, CHOICE, LIMIT)
      REAL CLO, ENTRY, GAMMAC, GAMMAI, HUMID, IMCLO, METAB, SKIN,
&      TEMPC,
&      WIND, DIH, DEHYD, TREND, WEX
      CHARACTER*2 CHOICE
      LOGICAL LIMIT
C
      IF (CHOICE .EQ. 'T' .OR. CHOICE .EQ. 't' .OR.
&      CHOICE .EQ. '1 ') THEN
21      WRITE(6,FMT='(1X)')
      WRITE(6,FMT='(1X,A11)')
&      ' Enter the Ambient Temperature in degrees',

```

```

&      ' Centigrade'
READ(5,*,ERR=21) ENTRY
IF (ENTRY .GE. -50. .AND. ENTRY .LE. 50.) THEN
    TEMPC=ENTRY
    RETURN
ELSE
    WRITE(6,FMT='(1X,A11,F6.3,A16)')
    &      ' THE ENTRY ',ENTRY,' IS OUT OF RANGE'
    GOTO 21
ENDIF
ELSE IF (CHOICE .EQ. 'H' .OR. CHOICE .EQ. 'h' .OR.
&      CHOICE .EQ. '2') THEN
22  WRITE(6,FMT='(1X)')
    WRITE(6,FMT='(1X,A36)')
    &      ' Enter the percent Relative Humidity'
    READ(5,*,ERR=22) ENTRY
    IF (ENTRY .GE. 0. .AND. ENTRY .LE. 100.) THEN
        HUMID=ENTRY
        RETURN
    ELSE
        WRITE(6,FMT='(1X,A11,F6.3,A16)')
        &      ' THE ENTRY ',ENTRY,' IS OUT OF RANGE'
        GOTO 22
    ENDIF
ELSE IF (CHOICE .EQ. 'W' .OR. CHOICE .EQ. 'w' .OR.
&      CHOICE .EQ. '3') THEN
23  WRITE(6,FMT='(1X)')
    WRITE(6,FMT='(1X,A38)')
    &      ' Enter the Wind Speed in meters/second'
    READ(5,*,ERR=23) ENTRY
    IF (ENTRY .GE. 0. .AND. ENTRY .LE. 10.) THEN
        IF (ENTRY .LT. .5) THEN
            ENTRY=.5
            WRITE(6,FMT='(1X,A38)')
            &      ' A NOMINAL WIND SPEED OF .5 M/SEC USED'
            WRITE(6,FMT='(1X)')
        ENDIF
        WIND=ENTRY
        RETURN
    ELSE
        WRITE(6,FMT='(1X,A11,F6.3,A16)')
        &      ' THE ENTRY ',ENTRY,' IS OUT OF RANGE'
        GOTO 23
    ENDIF
ELSE IF (CHOICE .EQ. 'M' .OR. CHOICE .EQ. 'm' .OR.
&      CHOICE .EQ. '4') THEN
24  WRITE(6,FMT='(1X)')
    WRITE(6,FMT='(1X,A34)')
    &      ' Enter the Metabolic Rate in Watts'
    READ(5,*,ERR=24) ENTRY
    IF (ENTRY .GE. 0. .AND. ENTRY .LE. 800) THEN
        IF (ENTRY .LT. 105.) THEN
            ENTRY=105.
            WRITE(6,FMT='(1X,A43)')
            &      ' A NOMINAL METABOLIC RATE OF 105 WATTS USED'
        ENDIF
        METAB=ENTRY
        RETURN
    ELSE
        WRITE(6,FMT='(1X,A11,F6.3,A16)')
        &      ' THE ENTRY ',ENTRY,' IS OUT OF RANGE'
        GOTO 24
    ENDIF
ELSE IF (CHOICE .EQ. 'WE' .OR. CHOICE .EQ. 'we' .OR.

```

```

25 & CHOICE .EQ. 'We' .OR. CHOICE .EQ. '5') THEN
WRITE(6,FMT='(1X)')
WRITE(6,FMT='(1X,A38)')
& ' Enter the External Work Rate in Watts'
READ(5,*,ERR=25) ENTRY
IF (ENTRY .GE. 0. .AND. ENTRY .LE. 800) THEN
WEX=ENTRY
RETURN
ELSE
WRITE(6,FMT='(1X,A11,F6.3,A16)')
& ' THE ENTRY ',ENTRY,' IS OUT OF RANGE'
GOTO 25
ENDIF
ELSE IF (CHOICE .EQ. 'C' .OR. CHOICE .EQ. 'c' .OR.
26 & CHOICE .EQ. '6') THEN
WRITE(6,FMT='(1X)')
WRITE(6,FMT='(1X,A43)')
& ' Enter the Clothing Insulation Value in Clo'
READ(5,*,ERR=26) ENTRY
IF (ENTRY .GE. .65 .AND. ENTRY .LE. 5.) THEN
CLO=ENTRY
RETURN
ELSE
WRITE(6,FMT='(1X,A11,F6.3,A16)')
& ' THE ENTRY ',ENTRY,' IS OUT OF RANGE'
GOTO 26
ENDIF
ELSE IF (CHOICE .EQ. 'I' .OR. CHOICE .EQ. 'i' .OR.
27 & CHOICE .EQ. '7') THEN
WRITE(6,FMT='(1X)')
WRITE(6,FMT='(1X,A46,A15)')
& ' Enter the effective permiability coefficient',
& 'known as Im/Clo'
READ(5,*,ERR=27) ENTRY
IF (ENTRY .GE. .0 .AND. ENTRY .LE. 1.) THEN
IMCLO=ENTRY
RETURN
ELSE
WRITE(6,FMT='(1X,A11,F6.3,A16)')
& ' THE ENTRY ',ENTRY,' IS OUT OF RANGE'
GOTO 27
ENDIF
ELSE IF (CHOICE .EQ. 'G' .OR. CHOICE .EQ. 'g' .OR.
28 & CHOICE .EQ. '8') THEN
WRITE(6,FMT='(1X)')
WRITE(6,FMT='(1X,A46,A25)')
& ' Enter the wind speed correction coefficient',
& 'GAMMA for CLO '
READ(5,*,ERR=28) ENTRY
IF (ENTRY .GE. .15 .AND. ENTRY .LE. .5) THEN
GAMMAC=ENTRY
RETURN
ELSE
WRITE(6,FMT='(1X,A11,F6.3,A16)')
& ' THE ENTRY ',ENTRY,' IS OUT OF RANGE'
GOTO 28
ENDIF
ELSE IF (CHOICE .EQ. 'G' .OR. CHOICE .EQ. 'g' .OR.
29 & CHOICE .EQ. '9') THEN
WRITE(6,FMT='(1X)')
WRITE(6,FMT='(1X,A46,A25)')
& ' Enter the wind speed correction coefficient',
& 'GAMMA Im/CLO'
READ(5,*,ERR=29) ENTRY

```

```

IF (ENTRY .GE. .15 .AND. ENTRY .LE. .5) THEN
  GAMMAI=ENTRY
  RETURN
ELSE
  WRITE(6,FMT='(1X,A11,F6.3,A16)')
  & ' THE ENTRY ',ENTRY,' IS OUT OF RANGE'
  GOTO 29
ENDIF
ELSE IF (CHOICE .EQ. 'S' .OR. CHOICE .EQ. 's' .OR.
30 & CHOICE .EQ. '10') THEN
  WRITE(6,FMT='(1X)')
  WRITE(6,FMT='(1X,A49)')
  & ' Enter the skin temperature in degrees Centigrade'
  READ(5,*,ERR=30) ENTRY
  IF (ENTRY .GE. 0. .AND. ENTRY .LE. 40.) THEN
    SKIN=ENTRY
    RETURN
  ELSE
    WRITE(6,FMT='(1X,A11,F6.3,A16)')
    & ' THE ENTRY ',ENTRY,' IS OUT OF RANGE'
    GOTO 30
  ENDIF
ELSE IF (CHOICE .EQ. 'DA' .OR. CHOICE .EQ. 'da' .OR.
31 & CHOICE .EQ. 'Da' .OR. CHOICE .EQ. '11') THEN
  WRITE(6,FMT='(1X)')
  WRITE(6,FMT='(1X,A29)')
  & ' Enter number of days in heat'
  READ(5,*,ERR=31) ENTRY
  IF (ENTRY .GE. 0.) THEN
    DIH = ENTRY
    RETURN
  ELSE
    WRITE(6,FMT='(1X,A11,F6.3,A16)')
    & ' THE ENTRY ',ENTRY,' IS OUT OF RANGE'
    GOTO 31
  ENDIF
ELSE IF (CHOICE .EQ. 'DE' .OR. CHOICE .EQ. 'de' .OR.
32 & CHOICE .EQ. 'De' .OR. CHOICE .EQ. '12') THEN
  WRITE(6,FMT='(1X)')
  WRITE(6,FMT='(1X,A27)')
  & ' Enter level of dehydration'
  READ(5,*,ERR=32) ENTRY
  IF (ENTRY .GE. 0.) THEN
    DEHYD = ENTRY
    RETURN
  ELSE
    WRITE(6,FMT='(1X,A11,F6.3,A16)')
    & ' THE ENTRY ',ENTRY,' IS OUT OF RANGE'
    GOTO 32
  ENDIF
ELSE IF (LIMIT .AND. (CHOICE .EQ. 'L') .OR.
40 & CHOICE .EQ. '1' .OR. CHOICE .EQ. '20') THEN
  WRITE(6,FMT='(1X)')
  WRITE(6,FMT='(1X,A43)')
  & ' Enter desired equilibrium core temperature'
  READ(5,*,ERR=40) ENTRY
  IF (ENTRY .GE. 36. .AND. ENTRY .LE. 42) THEN
    TREND = ENTRY
    RETURN
  ELSE
    WRITE(6,FMT='(1X,A11,F6.3,A16)')
    & ' THE ENTRY ',ENTRY,' IS OUT OF RANGE'
    GOTO 40
  ENDIF

```

```

ELSE
  WRITE(6,FMT='(1X,A12,A1,A19)')
  & ' THE ENTRY :',CHOICE,': IS NOT ACCEPTABLE'
  WRITE(6,FMT='(1X)')
  WRITE(6,FMT='(1X,A17)')
  & ' PLEASE TRY AGAIN'
ENDIF

C
RETURN
END

C **L**
FUNCTION LASTTM (TMBEG, TRBEG, TREND, TDELAY, DTREFA, CPEFF)
INTEGER LASTTM, TMBEG
REAL CPEFF, DTREF, DTREFA, K, TDELAY, TRBEG, TREND

C
DTREF=TREND-TRBEG

C
C Coefficient K is extracted from the work and recovery
C subroutines called by TRETIM
C
IF (DTREF .GT. 0.) THEN
  K=(1.+3.*EXP(-.3*(DTREF-DTREFA)))/120.
ELSE IF (DTREF .LT. 0.) THEN
  K=(1.-EXP(-1.5*ABS(CPEFF)))/40.
ELSE
  K=1.
ENDIF
IF (K .LT. .005) K=.005

C
C This formulation is the solution of the time dependent
C equations in WORK and RECOV subroutines
C and THE approximate solution that EXP(-ARG)=0
C WHEN ARG <=23.03
C
C As an expedient, assume that the time to reach essential
C equilibrium is no more than 240 minutes, therefore fix
C the smallest allowed value of K to that level.
C LASTTM=TMBEG+NINT(TDELAY+MIN(240.,23.03/K))
C
CR
CR WRITE(6,*) ' THE EQUILIBRIUM TIME WAS ',LASTTM
CR WRITE(6,*) ' FOR STARTING TRE OF ',TRBEG
CR WRITE(6,*) ' AND ENDING TRE OF ',TREND
CR WRITE(6,*) ' FOR CONDITIONS STARTED AT ',TMBEG
CR
RETURN
END

C **M**
SUBROUTINE MENU (CHOICE, DONE, RUN)
CHARACTER*2 CHOICE
LOGICAL DONE, LIMIT, RUN

C
100 CONTINUE
  CHOICE = ' '
  WRITE(6,FMT='(1X,A34)')
  & ' 99 Change the time to a new value'
  WRITE(6,FMT='(1X,A37)')
  & ' 0 Execute TCORE with current values'
  WRITE(6,FMT='(1X,A14)')
  & ' E Exit TCORE'
  WRITE(6,FMT='(1X,A28)')
  & ' SELECT A NUMBER TO CONTINUE'
  READ(5,'(A2)',ERR=100) CHOICE
C

```



```

IF (CHOICE .EQ. 'E' .OR. CHOICE .EQ. 'e') THEN
  DONE=.TRUE.
ELSE IF (CHOICE .EQ. 'O') THEN
  RUN=.TRUE.
ENDIF

```

```

RETURN
END

```

C **N**

```

SUBROUTINE NEWMET (METRAT,TREF,TREND,
& FIRST, TOHIGH, TOLOW)
REAL HIMET, LOMET, METRAT, TREF, TREND
LOGICAL FIRST, TOHIGH, TOLOW

```

```

TOLOW=.FALSE.
TOHIGH=.FALSE.
IF (FIRST) THEN
  HIMET=1000.
  LOMET=50.
  FIRST=.FALSE.
ENDIF

```

```

IF (METRAT .LT. LOMET .OR. METRAT .GT. HIMET) THEN
  STOP 'NEWMET HAS AN ERROR'
ENDIF

```

```

IF (TREF .GT. TREND) THEN
  HIMET=MIN(METRAT,HIMET)
  METRAT=(METRAT+LOMET)/2.
  IF (METRAT-LOMET .LT. .01) THEN
    TOLOW=.TRUE.
    WRITE(6,FMT='(1X,A30,1X,A27,2X, F4.0,A5)')
& 'These conditions would require',
& 'a metabolic rate lower than',LOMET,
& 'Watts'
  ENDIF

```

```

ELSE IF (TREF .LT. TREND) THEN
  LOMET=MAX(METRAT,LOMET)
  METRAT=(METRAT+HIMET)/2.
  IF (HIMET-METRAT .LT. .01) THEN
    TOHIGH=.TRUE.
    WRITE(6,FMT='(1X,A30,1X,A28,2X,F6.0,A5)')
& 'These conditions would require',
& 'a metabolic rate higher than',HIMET,
& 'Watts'
  ENDIF

```

```

ELSE
  WRITE(6,FMT='(1X,A23)') 'ERROR IN NEWMET ROUTINE'
ENDIF

```

```

RETURN
END

```

C **P**

```

SUBROUTINE PRBCAS(TRE,PROB)
REAL ERFCTN, MEAN, MODZ, PROBAB, STDDEV, SQRT2, TRE

```

```

PROBABILITY OF CASUALTY IS APPROXIMATED AS A CUMULATIVE
NORMAL DISTRIBUTION WITH THE MEAN EQUAL TO 39.5 AND THE
STD. DEV. EQUAL TO .5198
  (THE BEST FIT TO THE NIOSH AND PANDOFF DATA)

```

```

SQRT2=SQRT(2.)
MEAN = 39.5
STDDEV = .5198

```

MODZ = (TRE-MEAN)/STDDEV * 1/SQRT2

PROB = ERFCTN(MODZ)

PROB = AMAX1(PROB,0.)

PROB = AMIN1(PROB,100.)

RETURN

END

C ** P **

SUBROUTINE PLOT (VALUE, SCREEN, TMAX, TMIN,
& COLMAX, COLMIN, ROWMAX, ROWMIN)
& INTEGER COUNT, I, MAXT, ROWMAX, ROWMIN, COLMAX, COLMIN,
& X, Y
REAL TIM, TMAX, TMIN, VALUE, XSCALE, YSCALE, SCALE
CHARACTER*1 SCREEN, HIT, MISS
LOGICAL WRONG

DIMENSION SCREEN(24,80), VALUE(2,2048)

HIT='O'

MISS='*'

TIM=0.

COUNT=0

DO 10 I=1,1024

IF (I .EQ. 1 .OR.

& (I .GT. 1 .AND. VALUE(2,I) .GT. 0.)) THEN

TIM=MAX(VALUE(1,I),TIM)

COUNT=COUNT+1

ENDIF

10 CONTINUE

WRITE(6,*) ' THE VALUE OF COUNT IS ',COUNT

WRITE(6,*) ' AND THE TIME IS ',TIM

CALL SCALER (TIM, SCALE)

WRITE(6,*) ' THE SCALE FOR THE X AXIS IS ',SCALE

XSCALE=FLOAT(COLMAX-COLMIN)/SCALE

CALL XAXIS (SCREEN, COLMIN, COLMAX, ROWMAX, SCALE)

YSCALE=REAL(ROWMAX-ROWMIN)/REAL(NINT(TMAX)-INT(TMIN))

WRITE(6,*) ' THE VALUE OF XSCALE & YSCALE IS ',

& XSCALE, ' ',YSCALE

DO 20 I=1,COUNT

WRONG=.FALSE.

X=COLMIN+NINT(XSCALE*VALUE(1,I))

Y=ROWMAX-NINT(YSCALE*(VALUE(2,I)-TMIN))

IF (X .LT. COLMIN .OR. X .GT. COLMAX) THEN

WRITE(6,FMT='(1X,A15,I2,A18,I2,A1,I2,A2)')

& 'THE X VALUE OF ',X,' IS OUT OF RANGE [' ,

& COLMIN, ' ',COLMAX, '] '

WRONG=.TRUE.

ENDIF

IF (Y .LT. ROWMIN .OR. Y .GT. ROWMAX) THEN

WRITE(6,FMT='(1X,A15,I2,A18,I2,A1,I2,A2)')

& 'THE Y VALUE OF ',Y,' IS OUT OF RANGE [' ,

```

CR      &      ROWMIN, ',', ROWMAX, ']'
        WRONG=.TRUE.
        ENDIF
C
        IF (.NOT. WRONG) THEN
            SCREEN(Y,X) = HIT
        ELSE IF (WRONG .AND.
&          X .GE. COLMIN .AND. X .LE. COLMAX) THEN
            IF (Y .LT. ROWMIN) THEN
                SCREEN(ROWMIN,X)=MISS
            ELSE IF (Y .GT. ROWMAX) THEN
                SCREEN(ROWMAX,X)=MISS
            ENDIF
        ELSE IF (WRONG .AND.
&          Y .GE. ROWMIN .AND. Y .LE. ROWMAX) THEN
            IF (X .LT. COLMIN) THEN
                SCREEN(Y,COLMIN)=MISS
            ELSE IF (X .GT. COLMAX) THEN
                SCREEN(Y,COLMAX)=MISS
            ENDIF
        ELSE IF (X .LT. COLMIN .AND. Y .LT. ROWMIN) THEN
            SCREEN(ROWMIN,COLMIN)=MISS
        ELSE IF (X .LT. COLMIN .AND. Y .GT. ROWMAX) THEN
            SCREEN(ROWMAX,COLMIN)=MISS
        ELSE IF (X .GT. COLMAX .AND. Y .LT. ROWMIN) THEN
            SCREEN(ROWMIN,COLMAX)=MISS
        ELSE IF (X .GT. COLMAX .AND. Y .GT. ROWMAX) THEN
            SCREEN(ROWMAX,COLMAX)=MISS
        ENDIF
CR      WRITE(6,*) ' FOR TIME=',VALUE(1,I),' THE TEMP=',VALUE(2,I)
CR      WRITE(6,*) ' FOR ROW ',Y,' AND COLUMN ',X
CR      WRITE(6,*) ' THE VALUE IS :',SCREEN(Y,X),':'
CR
20      CONTINUE
C
        RETURN
        END
C **R**
        SUBROUTINE RACTIV (TEMPC, HUMID, WIND, METAB, WEX,
&          CLO, IMCLO, GAMMAC, GAMMAI, SKIN, DEHYD,
&          DIH, TIME, TREND, EQUIL, DONE,
&          LIMIT)
C*****
C      Subroutine interactive queries the user, in menu style,
C      as to whether the user wishes to 1) change input variables,
C      2) run TCORE (calculate Equilibrium Core Temperature and
C      PRBCAS) or 3) exit TCORE
C      Referenced by: Main Program
C      External Reference: None
C*****
        INTEGER EQUIL, T
        REAL CLO, ENTRY, GAMMAC, GAMMAI, HUMID, IMCLO, METAB, SKIN,
&          TEMPC, WIND, DIH, DEHYD, TIME, TREND, WEX
        CHARACTER*2 CHOICE
        LOGICAL DONE, LIMIT, RUN
C
        DIMENSION TEMPC(128), HUMID(128), WIND(128), METAB(128),
&          WEX(128), CLO(128), IMCLO(128), GAMMAC(128),
&          GAMMAI(128),
&          SKIN(128), DEHYD(128), DIH(128), TIME(128)
C
C
C
C

```

T=1
EQUIL=T

100 CALL DISPLA (TEMPC(T), HUMID(T), WIND(T), METAB(T), WEX(T),
& CLO(T), IMCLO(T), GAMMAC(T), GAMMAI(T), SKIN(T),
& DEHYD(T),
& DIH(T), TIME(T), TREND, LIMIT)

RUN=.FALSE.

200 CALL MENU (CHOICE, DONE, RUN)

IF (DONE .OR. RUN) THEN
RETURN

ELSE IF (CHOICE .EQ. '99' .OR. CHOICE .EQ. 'TI' .OR.
& CHOICE .EQ. 'ti' .OR. CHOICE .EQ. 'ti') THEN

IF (LIMIT) THEN

WRITE(6,FMT='(1X,A30,A30)')

'TIME CHANGES NOT ALLOWED WHEN ',
'SELECTING METABOLIC RATE LIMIT'

GOTO 100

ENDIF

T=T+1

300 WRITE(6,FMT='(1X)')

WRITE(6,FMT='(1X,A46)')

' Enter the beginning time for these conditions'

READ(5,*,ERR=300) TIME(T)

IF (TIME(T) .LT. TIME(T-1) .OR. TIME(T) .GT. 1440.) THEN

WRITE(6,FMT='(1X,A11,F6.3,A16)')

' THE ENTRY ',TIME(T), ' IS OUT OF RANGE'

WRITE(6,FMT='(1X,A12,1X,I6,2X,A13,A6)')

'IT MUST BE >',TIME(T-1), 'AND LESS THAN',
' 1 DAY'

TIME(T)=0.

GOTO 300

ENDIF

WRITE(6,FMT='(1X)')

IF (T .GT. 126) THEN

WRITE(6,FMT='(1X,A29)') 'TOO MANY TIMES TO ADD ANOTHER'

WRITE(6,FMT='(1X,A16)') 'PLEASE TRY AGAIN'

GOTO 200

ENDIF

TEMPC(T)=TEMPC(T-1)

HUMID(T)=HUMID(T-1)

WIND(T)=WIND(T-1)

METAB(T)=METAB(T-1)

WEX(T)=WEX(T-1)

CLO(T)=CLO(T-1)

IMCLO(T)=IMCLO(T-1)

GAMMAC(T)=GAMMAC(T-1)

GAMMAI(T)=GAMMAI(T-1)

SKIN(T)=SKIN(T-1)

DEHYD(T)=DEHYD(T-1)

DIH(T)=DIH(T-1)

EQUIL=T

GOTO 100

ENDIF

500 CALL INPUT (TEMPC(T), HUMID(T), WIND(T), METAB(T), WEX(T),
& CLO(T), IMCLO(T), GAMMAC(T), GAMMAI(T), SKIN(T),
& DEHYD(T),

& DIH(T), TREND, CHOICE, LIMIT)

GOTO 100

RETURN

END

C ** R **

SUBROUTINE RECOV (TRET, TREO, DTREF, TIME, DELAY, RISE,
& DELT, CPEFF)

INTEGER DELT

REAL CPEFF, DELAY, DTREF, KRCY, OLDTRE, RISE,

& TREO, TRET, TIME

The exponential coefficient for cooling after the appropriate
delay uses the absolute value of the CPEFF. The delay time
equation -- $DELAY = 15 * \exp(-0.5 * CPEFF)$ where
CPEFF ≥ 0 and
DELAY=15 where
CPEFF < 0

Further note that during the delay time, the core temperature
continues to rise at 1/2 the rate per minute that it was
rising during the previous time period and that the maximum
core temperature that will be achieved will ultimately be
used to define the delta that will be used by the recovery
period.

(Conversation with Mr. Leander Stroschein on 27 April
1990.)

OLDTRE=TRET

KRCY=(1.-EXP(-1.5*ABS(CPEFF)))/40.

IF (CPEFF .LT. 0.) WRITE(6,FMT='(1X,A19,F6.2,A19)')
& 'THE VALUE OF CPEFF ',CPEFF,' WAS LESS THAN ZERO'

IF (TIME .GT. DELAY .OR. DELAY .EQ. 0) THEN
TRET=TREO + DTREF*(1.-EXP(-KRCY*(TIME-DELAY)))
IF (DELT .GT. 0) RISE=(TRET-OLDTRE)/REAL(DELT)

ELSE
TRET=TREO + RISE * (DELAY-TIME)/DELAY +
& DTREF*(1.-EXP(-KRCY))*TIME/DELAY
ENDIF

WRITE(6,*) ' FOR RESTING TIME=',TIME
WRITE(6,*) ' THE STARTING CORE TEMPERATURE OF ',TREO
WRITE(6,*) ' AND THE ENDING CORE TEMPERATURE OF ',TREO+DTREF
WRITE(6,*) ' RESULTED IN A TEMPERATURE OF ',TRET

RETURN

END

C ** R **

SUBROUTINE RESULT (VALUE)

INTEGER I, ROWMIN, ROWMAX, COLMIN, COLMAX, MAXT, N
REAL TMAX, TMIN, VALUE, MAXTRE, CASUAL
CHARACTER*1 ANS, SCREEN, POINT, HIT, MISS

PARAMETER (ROWMIN=1,ROWMAX=21,COLMIN=4,COLMAX=79,
& TMAX=41.,TMIN=37.)

```

DIMENSION SCREEN(24,80), VALUE(2,2048)

MAXTRE=0.

CALL SET (SCREEN, COLMIN, COLMAX, ROWMIN, ROWMAX, TMAX, TMIN)

DO 100 N=1,2048
  CONTINUE
  WRITE(6,FMT='(1X,I4,1X,A29)')
    & N-1,'DATA POINTS IN THE INPUT FILE'
  WRITE(6,FMT='(1X)')
  WRITE(6,FMT='(1X,A32,A40)')
    & 'ENTER THE VALUES YOU WOULD LIKE ',
    & 'TO DISPLAY (TIME,TEMP) [999,999] TO PLOT'
  READ(5,*,ERR=2) VALUE(1,N),VALUE(2,N)
  WRITE(6,FMT='(1X)')

  WRITE(6,*) ' PROCESSING VALUE ',N
  WRITE(6,*) ' TIME ',VALUE(1,N)
  WRITE(6,*) ' TRET ',VALUE(2,N)

  IF (ABS(VALUE(1,N)-999.) .LT. 1. .AND.
    & ABS(VALUE(2,N)-999.) .LT. 1.) THEN
    DO 5 I=N,2048
      VALUE(1,N)=0.
      VALUE(2,N)=0.
    CONTINUE

    CALL PLOT (VALUE, SCREEN, TMAX, TMIN,
    & COLMAX, COLMIN, ROWMAX, ROWMIN)
    CALL SHOW(SCREEN)
    CALL PRBCAS(MAXTRE,CASUAL)

    WRITE(6,FMT='(1X,A37)')
    & 'DO YOU WANT TO SAVE THIS GRAPH (Y/N)?'
    READ(5,FMT='(A1)',ERR=19) ANS
    WRITE(6,FMT='(1X)')

    IF (ANS .EQ. 'Y' .OR. ANS .EQ. 'y')
    & CALL SAVE(VALUE, SCREEN, CASUAL, MAXTRE, N)

    WRITE(6,FMT='(1X,A13,2X,F6.2,A28,F6.2,A2,6X,A15)')
    & 'CASUALTIES = ',CASUAL,
    & '% THE HIGHEST CORE TEMP OF ',MAXTRE,
    & 'OC','FINISHED (Y/N)?'

    READ(5,'(A1)',ERR=20) ANS

    IF (ANS .EQ. 'Y' .OR. ANS .EQ. 'y') THEN
      STOP
    ELSE IF (ANS .EQ. 'N' .OR. ANS .EQ. 'n') THEN
      WRITE(6,FMT='(1X,A31)')
      & 'DO YOU WANT TO REDISPLAY (Y/N)?'
      READ(5,'(A1)',ERR=20) ANS
      IF (ANS .EQ. 'Y' .OR. ANS .EQ. 'y') THEN
        GOTO 10
      ELSE
        RETURN
      ENDIF
    ELSE
      GOTO 20
    ENDIF
  ENDIF
ENDIF

```

```

C
  IF (VALUE(1,N) .LT. 0. .OR.
    &   VALUE(2,N) .LT. 35. .OR. VALUE(2,N) .GT. 45.) THEN
    WRITE(6,FMT='(1X,A22,I4,A14,I4,A5,A32,A10)')
    &   ' THE VALUE ENTERED OF ',INT(VALUE(2,N)),
    &   ' AT A TIME OF ',INT(VALUE(1,N)), ' min ',
    &   ' IS NOT A VALID CORE TEMPERATURE',
    &   ' (OR TIME)'
    ENDIF
    MAXTRE=MAX(MAXTRE,VALUE(2,N))
C
100 CONTINUE
C
  RETURN
  END
C **S**
  SUBROUTINE SAVE (VALUE, SCREEN, CASUAL, MAXTRE, N)
    INTEGER I, IT, J, N
    REAL CASUAL, MAXTRE, VALUE
    CHARACTER*1 ANS, SCREEN
    CHARACTER*12 FILENAME
    CHARACTER*79 LABEL
C
    DIMENSION SCREEN(24,80), VALUE(2,2048)
C
C This subroutine gets a filename and a label to be placed
C in an output file which contains the graphic output,
C the level of casualties and the maximum core temperature,
C and the value of core temperature at every time during
C model execution.
C
10  WRITE(6,FMT='(1X,A25)') 'ENTER NAME OF GRAPH FILE:'
    READ(5,FMT='(A12)',ERR=10) FILENAME
    WRITE(6,FMT='(1X)')
11  WRITE(6,FMT='(1X,A27)') 'ENTER A LABEL FOR THE FILE:'
    READ(5,FMT='(A79)',ERR=11) LABEL
    WRITE(6,FMT='(1X)')
C
    OPEN(11,FILE=FILENAME,ERR=10)
    REWIND 11
C
    WRITE(11,FMT='(1X,A79)') LABEL
    WRITE(11,FMT='(1X)')
    DO 15 I=1,23
      WRITE(11,FMT='(1X,79A1)') (SCREEN(I,J),J=1,79)
15  CONTINUE
C
16  WRITE(11,FMT='(1X)')
    WRITE(11,FMT='(1X,A13,2X,F6.2,A29,F6.2,A2)')
    &   'CASUALTIES = ',CASUAL,
    &   '% FOR A HIGHEST CORE TEMP OF',MAXTRE,
    &   'OC'
    WRITE(6,FMT='(1X,A19,A36)') 'DO YOU WANT TO SAVE',
    &   ' TEMPERATURE VS. TIME PROFILE (Y/N)?'
C
    READ(5,FMT='(A1)',ERR=16) ANS
    WRITE(6,FMT='(1X)')
C
    IF (ANS .EQ. 'y' .OR. ANS .EQ. 'Y') THEN
      WRITE(11,FMT='(1X,A10,3X,A30)')
    &   'TIME','CORE TEMPERATURE'
      WRITE(11,FMT='(1X,A10,3X,A30)')
    &   '-----','-----'

```

```

WRITE(11,FMT='(1X)')
DO 17 IT=1,N-1
  WRITE(11,FMT='(1X,F10.2,3X,F20.2)')
  &      VALUE(1,IT),VALUE(2,IT)
17 CONTINUE
ENDIF
CLOSE(11)
RETURN
END
C ** S **
SUBROUTINE SCALER (TIM,SCALE)
REAL TIM, SCALE

IF (TIM .LE. 1.) THEN
  SCALE=1.
ELSE IF (TIM .LE. 5.) THEN
  SCALE=5.
ELSE IF (TIM .LE. 10.) THEN
  SCALE = 10.
ELSE IF (TIM .LE. 50.) THEN
  SCALE = 50.
ELSE IF (TIM .LE. 100.) THEN
  SCALE = 100.
ELSE IF (TIM .LE. 500.) THEN
  SCALE = 500.
ELSE
  SCALE = TIM
ENDIF

RETURN
END
C ** S **
SUBROUTINE SET (SCREEN,COLMIN,COLMAX,ROWMIN,ROWMAX,TMAX,TMIN)
INTEGER COLMIN, COLMAX, I, J, ROWMIN, ROWMAX
REAL TMAX, TMIN
CHARACTER*1 SCREEN, LINE

DIMENSION SCREEN(24,80), LINE(3)

LINE(1)='| '
LINE(2)='- '

DO 20 I=1,24
  DO 10 J=1,80
    SCREEN(I,J)=' '
  10 CONTINUE
20 CONTINUE

DO 30 I=ROWMIN,ROWMAX
  SCREEN(I,COLMIN)=LINE(1)
30 CONTINUE

DO 40 J=COLMIN,COLMAX
  SCREEN(ROWMAX,J)=LINE(2)
40 CONTINUE

SCREEN(1,8)='C'
SCREEN(1,9)='O'
SCREEN(1,10)='r'
SCREEN(1,11)='e'
SCREEN(1,13)='T'

```



```

SCREEN(1,14)='e'
SCREEN(1,15)='m'
SCREEN(1,16)='p'
SCREEN(1,17)='e'
SCREEN(1,18)='r'
SCREEN(1,19)='a'
SCREEN(1,20)='t'
SCREEN(1,21)='u'
SCREEN(1,22)='r'
SCREEN(1,23)='e'
SCREEN(1,25)='('
SCREEN(1,26)='o'
SCREEN(1,27)='c'
SCREEN(1,28)=')'
SCREEN(23,36)='T'
SCREEN(23,37)='i'
SCREEN(23,38)='m'
SCREEN(23,39)='e'
SCREEN(23,41)='('
SCREEN(23,42)='m'
SCREEN(23,43)='i'
SCREEN(23,44)='n'
SCREEN(23,45)=')'

```

```

CALL YAXIS(SCREEN, ROWMIN, ROWMAX, COLMIN, TMIN, TMAX)

```

```

RETURN
END

```

```

C ** S **

```

```

SUBROUTINE SHOW (SCREEN)
INTEGER I,J
CHARACTER*1 SCREEN

```

```

DIMENSION SCREEN(24,80)

```

```

DO 20 I=1,23
  WRITE(6,FMT='(1X,79A1)') (SCREEN(I,J),J=1,79)
20 CONTINUE

```

```

RETURN
END

```

```

C **T**

```

```

SUBROUTINE TCORE(AREA, CLO, DEHYD, DIH, PATM,
& GAMMAC, GAMMAI, HUMID, IMCLO,
& METAB, WEX, SKIN, TEMPC, WIND,
& TREF, TAU, TLAG, PCAS, DTREFA, M,
& EDIF)

```

```

C*****

```

```

  Subroutine TCORE performs all calculations required
  to determine Equilibrium Core Temperature as a function
  of heat stress.

```

```

  Rate equations taken from ED-SP-75011. Acclimatization
  equations from W. Matthews, USARIEM, December 1989.

```

```

  Referenced by: Main Program

```

```

  External Reference: ERFCTN

```

```

C*****

```

```

REAL A, AREA, B, C, CLO, CLOSTR, D, DEHYD, DELT, DF, DIH,
& DTREFA, DTREFD, EMAX, EREQ, EDIF, GAMMAC, GAMMAI,
& HUMID, IMCLO, IMSTR, M, MEAN, METAB, MODZ, PATM, PCAS,
& PS, PW, SKIN, STDDEV, T, TAU, TLAG,
& TEMPC, TREF, VEFF, WIND, X, XP
DATA A,B,C,D /3.2437814, 5.86826E-3, 1.1702379E-8,
& 2.1878462E-3 /

```

CALCULATE ENERGY EXPENDITURE SENSITIVE PARAMETERS

M=METAB-WEX

CALCULATE WIND SPEED SENSITIVE PARAMETERS

VEFF = WIND + 0.004*(METAB-105.)

CLOSTR = CLO*VEFF**(-GAMMAC)

IMSTR = IMCLO*VEFF**GAMMAI

CALCULATION OF THE SATURATION WATER PRESSURE PW
AND THE VAPOR PRESSURE OVER THE SKIN PS WHEN=>
T IS THE ABSOLUTE TEMPERATURE
A, B, C, AND D ARE COEFFICIENTS FOR AN
EMPIRICAL CALCULATION
AND X AND XP ARE INTERMEDIATE VALUES.

T = TEMPC+273.16

X = 647.27-T

XP = (X/T)*((A+B*X+C*X**3)/(1.+D*X))

PW = 218.167*10**(-XP) * PATM

T = SKIN+273.16

X = 647.27-T

XP = (X/T)*((A+B*X+C*X**3)/(1.+D*X))

PS = 218.167*10**(-XP) * PATM

CALCULATE WET HEAT EXCHANGE COMPONENTS

EREQ = M + 6.47*AREA*(TEMPC-SKIN)/CLOSTR

EMAX = 14.21*AREA*IMSTR*(PS-0.01*HUMID*PW)

EDIF= EMAX-EREQ

IF (EDIF .LT. 0) THEN

WRITE(6,*) ' EDIF WAS FOUND TO BE ',EDIF

WRITE(6,*) ' WHEN M = ',M, ' TEMPC = ',TEMPC,

& ' AND RELATIVE HUMIDITY = ',HUMID

ENDIF

THE COEFFICIENT FOR H(R+C)

WAS ORIGINALLY .014(.0022x6.45)

BUT WAS MODIFIED TO .0011x6.45 (.01095) per L. Stroschein)

TREF = 36.75 + 0.004*M +

& (0.0011*6.45*AREA/CLOSTR)*(TEMPC-SKIN)+

& 0.8*EXP(0.0047*(- EDIF))

CALCULATE EFFECTS OF ACCLIMATIZATION ON CORE TEMPERATURE

DTREFA = (0.5 + 1.2 * (1.0 - EXP((37.15 - TREF)/2.0)))

& * (1.0 - EXP(-.005*EMAX)) * (EXP(-0.3 * DIH))

CALCULATE EFFECTS OF DEHYDRATION ON CORE TEMPERATURE

REGRESSION EQUATION BASED ON MICHAEL N. SAWKA

REPORT, "THERMOREGULATORY AND BLOOD RESPONSES

DURING EXERCISE AT GRADED HYPOHYDRATION LEVELS"

*** CAUTION!!! THE FOLLOWING EQUATIONS FOR DEHYDRATION

*** ARE JUST A TEST CASE. FURTHER INVESTIGATION IS

```

C      **** BEING DONE TO VERIFY THIS ALGORITHM
C
C      DTREFD = (0.1735) * DEHYD - 0.215
C
C      *** DEHYDRATION >= 5% IS REPORTED TO COMPLETELY
C      *** REDUCE THE EFFECT OF ACCLIMATIZATION.
C      *** AS A RESULT, THE FOLLOWING FUNCTION IS
C      *** BEING EVALUATED AGAINST THE DATA
C      *** TO MODIFY THE DIH VALUE
C
C      DF= MIN(1.,DEHYD/5.)
CR
CR      WRITE(6,*) ' THE VALUE OF EXP((37.15-TREF)/2) ',
CR      &          'FOR TREF=',TREF,' IS ',EXP((37.15 - TREF)/2.)
CR      WRITE(6,*) ' THE VALUE OF EXP(-.005*EMAX ',
CR      &          'FOR EMAX=',EMAX,' IS ',EXP(-.005*EMAX)
CR      WRITE(6,*) ' THE VALUE OF EXP(-0.3*DIH)',
CR      &          'FOR DIH=',DIH,' AND DF=',DF,' IS ',
CR      &          EXP(-0.3*DIH*(1.-DF))
CR
C      DTREFA = (0.5 + 1.2 * (1.0 - EXP((37.15 - TREF)/2.0)))
C      &      *(1.0 - EXP(-.005*EMAX)) * (EXP(-0.3*DIH*(1.-DF)))
C
C      *** THE ABOVE EQUATIONS FOR DEHYDRATION
C      *** ARE STILL BEING TESTED FOR VALIDITY
C
C      TREF = TREF + DTREFA + DTREFD
C      DELT = TREF - 36.75
C      CALL PRBCAS(TREF,PCAS)
C      TAU = 0.5 + 1.5*EXP(-0.3*DELT)
C      TLAG = 58./METAB
C
C      RETURN
C      END
C ** T **
C      SUBROUTINE TRETIM (VALUE, TIME, TREF, DTREFA, M, EDIF,
C      &                  EQUIL, LIMIT)
C      INTEGER ENTRY, EQUIL, DELTIM, DELT, I, LAST, LASTTM,
C      &      OLDTIM, START, T, TMBEG, TMEND
C      REAL CPEFF, M, ED, EDIF, DELTM, DTREF, DTREFA,
C      &      RISE, TDELAY, TIM, TIME,
C      &      TRBEG, TREF, TREND, TRET, VALUE
C      CHARACTER*1 ANS
C      LOGICAL DELAY, LIMIT, NEWMET, REPEAT, REST
C
C      DIMENSION VALUE(2,2048)
C      DIMENSION M(128), TIME(128), TREF(128), EDIF(128)
C
C      DELTIM=MAX(5,INT(TIME(EQUIL))/1024)
C      OLDTIM=0
C
C      WRITE(6,FMT='(1X)')
C      IF (.NOT. LIMIT) THEN
C      10  WRITE(6,FMT='(1X,A45,1X,I5,1X,A12)')
C      &      'DO YOU WANT TO CHANGE THE TIME INTERVAL FROM',
C      &      DELTIM,'(min)? (Y/N)'
C      READ(5,FMT='(A1)',ERR=10) ANS
C      WRITE(6,FMT='(1X)')
C      ENDIF
C
C      20 IF (ANS .EQ. 'N' .OR. ANS .EQ. 'n'.OR. LIMIT) THEN

```

```

LAST=0
TRET=37.
RISE=0.
DO 30 I=1,2048
  VALUE(1,I)=0.
  VALUE(2,I)=0.
  CONTINUE

```

```

DO 100 I=1,EQUIL

```

```

  NEWMET=.FALSE.

```

```

  Set the rest flag if the people are not at work
  to start a recovery period

```

```

    IF (M(I) .LE. 105.) THEN
      REST=.TRUE.
    ELSE
      REST=.FALSE.
    ENDIF

```

```

  Set the begining time for each assessment cycle
  Use the NEWMET flag to identify a change in
  metabolic rate. This flag is used to assert weather
  or not a time delay is used in calculating the change
  in core temperature values.

```

```

    IF (I .EQ. 1) THEN
      TMBEG=0
      NEWMET=.TRUE.
    ELSE
      TMBEG=INT(TIME(I))
      IF (ABS(M(I)-M(I-1)) .GE. 1.) NEWMET=.TRUE.
    ENDIF

```

```

  Set the time delay. For recovery periods the time
  delay is based on the cooling power (set by
  the difference between Ereq and Emax.
  The time delay for the work conditions is based on
  the change in the level of energy expenditures
  No time delay is generated for work at the same
  energy expenditure.

```

```

    IF (REST) THEN
      CPEFF=0.015*EDIF(I)
      TDELAY=MIN(15.,15.*EXP(-0.5*CPEFF))
    ELSE
      IF (I .EQ. 1) THEN
        TDELAY=3480./M(1)
      ELSE IF (NEWMET) THEN
        TDELAY=3480./(105.+ABS(M(I)-M(I-1)))
      ELSE
        TDELAY=0.
      ENDIF
    ENDIF

```

```

    TRBEG=TRET
    IF (I .LT. EQUIL) THEN
      TREND=TREF(I)
      TMEND=INT(TIME(I+1))
    ELSE IF (I .EQ. EQUIL) THEN
      TREND=TREF(EQUIL)
      TMEND=LASTTM(TMBEG, TRBEG, TREND, TDELAY,
        DTREFA, CPEFF)
    &

```

```
ENDIF
DTREF=TREND-TRBEG
```

```
IF (TDELAY .GT. REAL(TMEND-TMBEG))
  WRITE(6,FMT='(1X,A11,F7.2,A22,I5,A5,
    I5,A8,/,1X,A17,A30)')
    'A DELAY OF ',TDELAY,
    ' IS NECESSARY BETWEEN ',TMBEG,' AND ',
    TMEND,' minutes','TO ACCOMPLISH THE',
    ' APPROPRIATE CHANGE IN ACTIVITY'
```

```
WRITE(6,*) ' LOOPING FOR TIME # ',I
WRITE(6,*) ' THE RANGE OF TIMES ARE [',TMBEG,TMEND,']'
WRITE(6,*) ' THE RANGE OF TRES ARE [',TRBEG,TREND,']'
```

```
DELAY=.FALSE.
REPEAT=.FALSE.
```

```
IF (I .EQ. 1) THEN
  START=0
ELSE
  START=TMBEG+1
ENDIF
```

```
IF (INT(TDELAY) .GT. 0) THEN
  DO 80 T=START,TMBEG+INT(TDELAY)
```

The logic that follows allows the delta in core temperature, DTREF, to vary during the delay time. While the equilibrium value remains the same, the core temperature calculated at any time, TRET, is modified during a change in metabolic rate (from changing the work load or from starting a recovery time period. Note that the temperature at the delay time is always calculated as long as it occurs before the end of the time window being portrayed.

(Conversation with Mr. Leander Stroschein on 27 April 1990.)

```
TIM=REAL(T)
DELT=REAL(T-TMBEG)
DTREF=TREND-TRET
TRBEG=TRET
DELT=T-OLDTIM
OLDTIM=T
```

```
CALL ATTIME (TRET, TRBEG, DTREF, DTREFA, DELTM,
  DELT, TDELAY, RISE, CPEFF, LAST,
  TIM, VALUE, NEWMET, REST)
```

```
WRITE(6,*) ' IN LOOP 80  DELAY > 0 '
WRITE(6,*) ' FOR TIME OF ',TIM
WRITE(6,*) ' WITH A DELAY OF ',TDELAY
WRITE(6,*) ' TRET=',TRET,' DELTA TRE = ',DTREF
```

```
80 CONTINUE
  TRBEG=TRET
ENDIF
```

The DO 90 LOOP calculates the core temperature for time

increments of DELTIM from the end of the time delay (if any, to the final time.

```

      IF (INT(TDELAY) .GT. 0) THEN
        START=TMBEG+INT(TDELAY)+1
      ELSE IF (I .EQ. 1) THEN
        START=1
      ELSE
        START=TMBEG+1
      ENDIF

```

```

      DO 90 T=START, TMEND, DELTIM

```

```

        TIM=REAL(T)
        DELTM=REAL(T-TMBEG)
        DELT=T-OLDTIM
        OLDTIM=T

```

```

        CALL ATTIME (TRET, TRBEG, DTREF, DTREFA, DELTM,
&          DELT, TDELAY, RISE, CPEFF, LAST,
&          TIM, VALUE, NEWMET, REST)

```

```

        WRITE(6,*) ' IN LOOP 90 '
        WRITE(6,*) ' BETWEEN ', START,
&          ' AND ', TMEND
        WRITE(6,*) ' FOR TIME OF ', TIM
        WRITE(6,*) ' TRET=', TRET, ' DELTA TRE = ', DTREF

```

```

      90 CONTINUE

```

```

      IF (TIM .LT. REAL(TMEND)) THEN
        DELTM=REAL(TMEND-TMBEG)
        TIM=REAL(TMEND)
        DELT=TMEND-OLDTIM
        OLDTIM=TMEND

```

```

        CALL ATTIME (TRET, TRBEG, DTREF, DTREFA, DELTM,
&          DELT, TDELAY, RISE, CPEFF, LAST,
&          TIM, VALUE, NEWMET, REST)

```

```

        WRITE(6,*)
        WRITE(6,*) '          AT THE LAST TIME OF THE GROUP '
        WRITE(6,*) ' FOR TIME OF ', TIM
        WRITE(6,*) ' TRET=', TRET, ' DELTA TRE = ', DTREF

```

```

      ENDIF

```

```

100 CONTINUE

```

```

      ELSE IF (ANS .EQ. 'Y' .OR. ANS .EQ. 'y') THEN

```

```

110 WRITE(6,FMT='(1X,A39)')

```

```

&          'ENTER THE NEW TIME INTERVAL IN MINUTES:'

```

```

      READ(5,*,ERR=110) ENTRY

```

```

      IF (ENTRY .GT. 14400) THEN

```

```

        WRITE(6,FMT='(1X,I10,1X,A17)')

```

```

&          ENTRY, 'GREATER THAN 1 DAY'

```

```

        WRITE(6,FMT='(1X,A16)')

```

```

&          'PLEASE TRY AGAIN'

```

```

        WRITE(6,FMT='(1X)')

```

```

        GOTO 110

```

```

      ELSE IF (INT(TIME(EQUIL))/DELTIM .GT. 1024) THEN

```

```

        WRITE(6,FMT='(1X,I10,1X,A31,1X,A22)')

```

```

&          INT(TIME(EQUIL))/DELTIM,
&          'TIME PERIODS REQUESTED WHEN THE',

```

```

&      'MAXIMUM NUMBER IS 1024'
      WRITE(6,FMT='(1X)')
      WRITE(6,FMT='(1X,A22,1X,I5)')
&      'TRY A TIME LARGER THAN',
&      INT(TIME(EQUIL))/1024
      WRITE(6,FMT='(1X)')
      GOTO 110
    ELSE
      DELTIM=ENTRY
      GOTO 10
    ENDIF
  ENDIF
ENDIF

C
LAST=LAST+1
VALUE(1, LAST)=999.
VALUE(2, LAST)=999.

CR
CR
CR
C
RETURN
END
C **W**
SUBROUTINE WORK (TRET, TREO, DTREF, DTREFA, TIME, DELAY,
&      RISE, DELT, NEWMET)
  INTEGER DELT
  REAL DTREF, DTREFA, DTREFC, KWRK, DELAY, OLDTRE,
&      TREO, TRET, TIME
  LOGICAL NEWMET

  The exponential coefficient for the change of core temperature
  during work uses the change in core temperature without the
  benefit of acclimatization.

  The time delay equation -- DELAY = 3480 / M uses the value
  of net metabolic rate when there is a change of metabolic
  rate and DELAY = 0 if there is no change in metabolic
  rate.

  Further note that during the delay time, the core temperature
  continues to rise at 1/2 the rate per minute that it was
  rising during the previous time period and that the maximum
  core temperature that will be achieved will ultimately be
  used to define the delta that will be used by the recovery
  period.

  (Conversation with Mr. Leander Stroschein on 27 April
  1990.)

  OLDTRE=TRET
  DTREFC=MAX(0., DTREF-DTREFA)
  KWRK=(1.+3.*EXP(-.3*(DTREFC)))/120.

  CR
  CR
  CR
  C
  WRITE(6,*) ' KWRK ', KWRK, ' DTREF ', DTREF,
&      ' DTREFA ', DTREFA

  IF (TIME .GT. DELAY .OR. DELAY .EQ. 0. .OR.
&      .NOT. NEWMET) THEN
    TRET=TREO + DTREF*(1.-EXP(-KWRK*(TIME-DELAY)))
    IF (DELT .GT. 0) RISE=(TRET-OLDTRE)/REAL(DELT)

  CR
  CR
  WRITE(6,*) ' IN FIRST OPTION TRET=', TRET, ' RISE ', RISE

```

```

CR
CR ELSE
CR   TRET=TREO + RISE*(DELAY-TIME)/DELAY +
CR   & TIME/DELAY*DTREF*(1.-EXP(-KWRK))
CR
CR   WRITE(6,*) ' ',TREO,' IN SECOND OPTION TRET= ',TRET
CR   WRITE(6,*) ' FIRST TERM= ',RISE*(DELAY-TIME)/DELAY
CR   WRITE(6,*) ' SECOND TERM= ',TIME/DELAY*
CR   & DTREF*(1.-EXP(-KWRK))
CR   WRITE(6,*) ' RISE= ',RISE,' DELAY= ',DELAY,
CR   & ' TIME= ',TIME
CR
CR ENDIF
CR
CR   WRITE(6,*) ' FOR WORKING TIME=',TIME
CR   WRITE(6,*) ' THE STARTING CORE TEMPERATURE OF ',TREO
CR   WRITE(6,*) ' AND THE ENDING CORE TEMPERATURE OF ',TREO+DTREF
CR   WRITE(6,*) ' RESULTED IN A TEMPERATURE OF ',TRET
CR   WRITE(6,*) ' WITH A RATE OF RISE OF ',RISE
CR
CR RETURN
CR END
CR
CR **X**
CR SUBROUTINE XAXIS (SCREEN, COLMIN, COLMAX, ROWMAX, SCALE)
CR INTEGER COLMAX, COLMIN, I, ROWMAX, XTIC, XLABEL
CR REAL SCALE
CR CHARACTER*1 SCREEN
CR
CR DIMENSION SCREEN(24,80), XTIC(6), XLABEL(6)
CR
CR DO 10 I=1,6
CR   XTIC(I)=COLMIN + NINT((COLMAX-COLMIN)*FLOAT(I-1)/5.)
CR   IF (XTIC(I) .GT. COLMAX) THEN
CR     XTIC(I)=COLMAX
CR   ELSE IF (XTIC(I) .LT. COLMIN) THEN
CR     XTIC(I)=COLMIN
CR   ENDIF
CR
CR   SCREEN(ROWMAX,XTIC(I))='+'
CR   XLABEL(I)=NINT(SCALE*FLOAT(I-1)/5.)
CR
CR   WRITE(6,*) ' XTIC AT ',I,XTIC(I),' SHOULD BE ',XLABEL(I)
CR
CR   CALL DIGIT(XTIC(I), XLABEL(I), SCREEN, ROWMAX, 'X')
CR 10 CONTINUE
CR
CR RETURN
CR END
CR
CR **Y**
CR SUBROUTINE YAXIS(SCREEN, ROWMIN, ROWMAX, COLMIN, TMIN, TMAX)
CR INTEGER I, ROW, ROWMIN, ROWMAX, COLMIN
CR REAL TMIN, TMAX, YSCALE
CR CHARACTER*1 SCREEN, LINE
CR
CR DIMENSION SCREEN(24,80), LINE(3)
CR
CR LINE(3)='+'
CR
CR YSCALE=REAL(ROWMAX-ROWMIN)/REAL(NINT(TMAX)-INT(TMIN))
CR
CR DO 10 I=INT(TMIN),NINT(TMAX)
CR   IF (I .EQ. INT(TMIN)) THEN
CR     ROW=ROWMAX

```



```
ELSE IF (I .EQ. NINT(TMAX)) THEN
  ROW=ROWMIN
ELSE
  ROW=ROWMAX-NINT((REAL(I)-TMIN)*YSCALE)
ENDIF
```

```
SCREEN(ROW,COLMIN)=LINE(3)
CALL DIGIT(COLMIN, I, SCREEN, ROW, 'Y')
```

```
CONTINUE
```

```
RETURN
END
```

APPENDIX B
Example of Goldman-Givoni Input Files and Resulting Outputs

The Goldman-Givoni model, as used at SAIC, was written to be an interactive model. The model gives the user a menu with which the user can set the appropriate meteorological conditions, clothing type, work intensity, etc. for a specified time period. Table B-1 shows a portion of this menu.

Table B-1. Menu Choices from Goldman-Givoni Model		
Menu Choice	Description	Default Value
1	Ambient Temperature (°C)	20
2	Relative Humidity (%)	20
3	Wind Speed (m/s)	3
4	Metabolic Rate (Watts)	425
5	External Workload	0
6	Clo	1.13
7	Im/Clo	.43
8	Gamma for Clo	.26
9	Gamma for Im/Clo	.255
10	Skin Temperature (°C)	.38
11	Days of Acclimatization	12
12	Dehydration (%)	0
99	Beginning Time for Conditions (Minutes)	0

The following is an example of a file used as inputs for the Goldman-Givoni model. Inputs were stored in a file and subsequently used via file redirection to facilitate more reproducible results and to minimize potential input errors. The file begins with an "I" in answer to the Goldman-Givoni question: "(I)nteractive or Metabolic (L)imit mode?" After this, the inputs are set up with a Menu Choice (number shown in table above) followed by the desired value.

Goldman-Givoni Input File
Work/Rest Case, Unacclimatized and 5% Dehydration

I
1
31.1
2
46.4
3
2.9
4
425
11
0
12
5
99
45
4
105
99
60
4
425
99
105
4
105
99
120
4
425
99
165
4
105
99
180
4
425
99
225
4
105
99
240
4
425
99
285
4
105
99
300

Goldman-Givoni Input File (cont.)

4
425
99
345
4
105
99
360
4
425
99
405
4
105
99
420
4
425
1
35.6
2
34.1
3
4.6
99
465
4
105
99
480
4
425
99
525
4
105
99
540
4
425
99
585
4
105
99
600
4
425
99
645
4
105
99

Goldman-Givoni Input File (cont.)

660
4
425
1
40.9
2
20.26
3
6.4
99
705
4
105
99
720
4
425
99
765
4
105
99
780
4
425
99
825
4
105
99
840
4
425
99
885
4
105
99
900
4
425
1
39.1
2
21.4
3
6.1
99
945
4
105
99
960

Goldman-Givoni Input File (cont.)

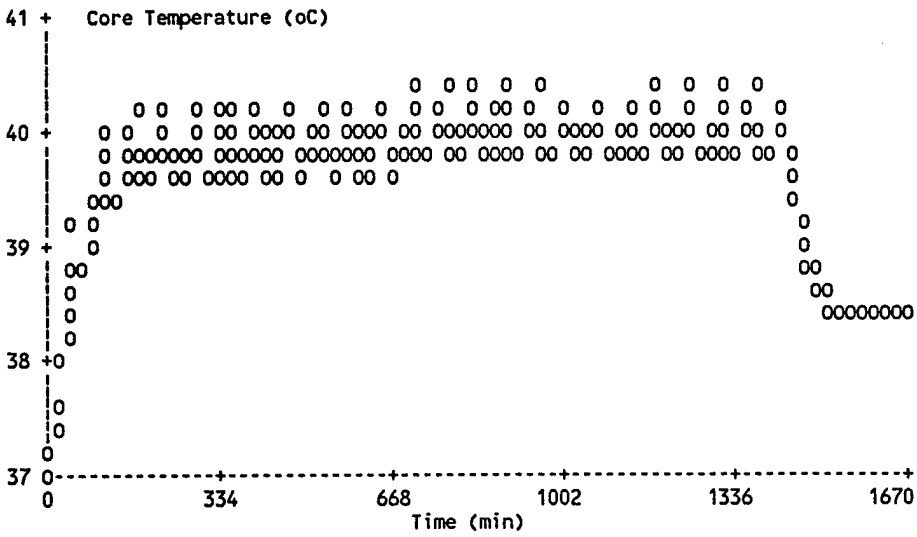
4
425
99
1005
4
105
99
1020
4
425
99
1065
4
105
99
1080
4
425
99
1125
4
105
99
1140
4
425
1
34.5
2
39.13
3
3.3
99
1185
4
105
99
1200
4
425
99
1245
4
105
99
1260
4
425
99
1305
4
105
99

Goldman-Givoni Input File (cont.)

1320
4
425
99
1365
4
105
99
1380
4
425
1
31.1
2
46.4
3
2.9
99
1425
4
105
0
N
Y
0510425.GPH
SW ASIA DAY -- A0D5 -- HIGHEST W/R FROM FM21-10 -- WMR: 425 WATTS
Y
Y

This input file produced a file containing a crude graph of core temperature vs. time and the corresponding table of values. Included below is the graph resulting from the above inputs and the data on Probability of Casualty and the highest core temperature achieved during the time period considered.

SW ASIA DAY -- A005 -- HIGHEST W/R FROM FM21-10 -- WMR: 425 WATTS



CASUALTIES = 95.19% FOR A HIGHEST CORE TEMP OF 40.36oC

APPENDIX C
Modeling of Medical Interventions

To develop the toxicologically significant values for use in this study, a series of meetings were held with U.S. Army Medical Research Institute of Chemical Defense (USAMRICD) personnel. Draft concepts were developed and documented in a 17 January 1989 memo to the Commander, COL Dunn, documenting our method of representing the toxicology values selected before they were used in this study.

Originally, Dr. Hackley, Dr. Bareis, and Mr. McNally met on 12 January to determine reasonable dose-effect relationships for soman-induced lethality and miosis. After a review of the published numbers, estimates of the best numbers to use in the Modular Chemical Assessment Structure (MCAS) model were made. These estimates were:

<u>Lethality:</u>	$LCT_{50} = 50 \text{ mg-min/m}^3$ (range 30-70)
	$LCT_{100} = 90 \text{ mg-min/m}^3$ (range 85-95)
<u>Miosis:</u>	Threshold = 0.2 mg-min/m^3
	$ECT_{50} = 1 \text{ mg-min/m}^3$

The lethality estimates were developed to estimate a probit slope of 0.1125 used in further calculations.

On 17 January 1989 COL (Dr.) Dunn met with Dr. Hackley, Dr. Bareis, and Mr. McNally to confirm the choice of toxicology values identified above and to estimate the impact of different therapy regimens. The first regimen consisted of a pyrisostigmine pretreatment, atropine, 2-PAM, and a hypothetical anticonvulsant therapy. The anticonvulsant was assumed to prevent brain damage and improve return to duty times. The effectiveness of the regimen was assessed as follows:

Dose range 0-0.5 LCT_{50} :	All survive, no loss of duty time.
Dose range 0.5-2 LCT_{50} :	All survive, return to duty in four days.
Dose range 2-5 LCT_{50} :	Return to duty in 10 days; 90% survival at 5 LCT_{50} .

No effect on miosis was attributed to use of this therapy.

A second regimen, using a monoclonal antibody pretreatment, was identified. A monoclonal antibody was projected to provide protection to a 5 LCT_{50} dose when administered. The plasma half-life was estimated to be six weeks. The assumption was made that the soldiers do not necessarily have a high antibody titer at the time of soman exposure. Therapy as described in regimen #1 was also available.

Dose range 0-1 LCT_{50} :	Soldiers are symptom-free; no MOPP needed.
Dose range > 1 LCT_{50} :	MOPP gear and antidotes may be required; return to duty in four days.

The above data was used as a starting point to develop the complete toxicology profile necessary for representing different medical therapy options within MCAS.

The toxicology model used was the probit model which is based on a linear relationship between the logarithm of the dose to the median dose for a particular level of effect and the percentage of the population that would exhibit that effect.

Using an approximation that the difference between 100% and 50% population response is 2.27 standard deviations (actually the difference between 98.8% and 50%), the probit slope, given an LCT_{100} of 90 and a LCT_{50} of 50, is 0.1125, which is based on the equation:

$$\text{probit slope} = \log (D_{98.8}/D_{50}) / 2.27$$

which then approximates the fundamental relationship:

$$\text{probit slope} = \log (D_{84}/D_{50}) / 1.0$$

generating the probit slope necessary to develop all of the remaining probability/dose response relationships.

The probit slope is used to calculate critical dose values based on the relationship

$$D_{xx} = D_{50} \times 10^{(\text{probit slope} \times \# \text{ of probits})}$$

where the # of probits is based on the probability involved. The difference between xx% and 50% probability response is assessed as the Z score associated with the normal probability distribution.

The probit approach can be used to calculate the LCT_{10} value as follows:

$$\begin{aligned} LCT_{10} &= D_{50}(50) \times 10^{(\text{probit slope}(0.1125) \times \# \text{ of probits}(-1.382))} \\ LCT_{10} &= 35 \text{ mg-min/m}^3 \end{aligned}$$

Without approved toxicology levels for incapacitation, a rule of thumb approximation was used to assess that the ICT_{50} value was approximately the same as the LCT_{10} value of 35 mg-min/ m^3 .

Values developed by Richard Saucier at the Chemical Research, Development, and Engineering Center (CRDEC) were used for percutaneous vapor and liquid toxicology values. These values were:

$$\begin{aligned} \text{Vapor } LCT_{50} &= 2900 \text{ mg-min/m}^3 \\ ICT_{50} &= 1900 \text{ mg-min/m}^3 \\ TCt_{50} &= 200 \text{ mg-min/m}^3 \\ \text{Liquid } LD_{50} &= 350 \text{ mg/man} \\ ID_{50} &= 207 \text{ mg/man} \\ TD_{50} &= 63 \text{ mg/man} \end{aligned}$$

For effectiveness assessment using the Army Unit Resiliency Analysis (AURA) model, the two key elements of input are the percentage of incapacitated personnel and duration of incapacitation. Nerve agents affect personnel with vision-dependent and, at lower levels, can further reduce effectiveness. For example, the ECT_{50} value of 1 mg-min/ m^3 was enough to incapacitate a person with vision intensive tasks while the remaining majority of personnel would respond based on an ICT_{50} value of 35 mg-min/ m^3 .

To represent the regimen based on pyridostigmine pretreatment, atropine, 2-PAM, and a hypothetical anticonvulsant, new critical toxicology values had to be calculated. Initially, a no incapacitation value (no loss of duty time), ICT_0 , was identified as $0.5 \times LCT_{50}$ or 25 mg-min/ m^3 . The new LCT_{10} value (90% survival) was identified as $5 \times LCT_{50}$ or 250 mg-min/ m^3 . Further, since the regimen was assumed to have no effect on miosis, the TCT_{50} eye value of 0.2 mg-min/ m^3 and the ECT_{50} eye value of 1 mg-min/ m^3 were assumed to be unchanged. The probit slope of 0.1125 was also assumed to be unchanged.

To calculate the LCT_{50} value, a distance of 1.382 probits was used from the LCT_{10} value of 250 mg-min/ m^3 , resulting in a value of 357 mg-min/ m^3 .

To calculate the ICT_{50} value, a distance of 2.27 probits was used from the ICT_0 value of 25 mg-min/ m^3 , resulting in a value of 45 mg-min/ m^3 .

To approximate the percutaneous liquid and vapor toxicology values, the ratio of the median response respiratory values for therapy versus without therapy was calculated. The resulting ratios were 7.14 for lethal effects, 1.28 for incapacitation effects, and 1.29 for threshold effects. These ratios were used to calculate new percutaneous values as follows:

$$\begin{aligned}\text{Vapor } LCT_{50} &= 2900 \times 7.14 = 21000 \text{ mg-min}/m^3 \\ ICT_{50} &= 1900 \times 1.29 = 2450 \text{ mg-min}/m^3 \\ TCT_{50} &= 200 \times 1.29 = 258 \text{ mg-min}/m^3\end{aligned}$$

$$\begin{aligned}\text{Liquid } LD_{50} &= 350 \times 7.14 = 2500 \text{ mg/man} \\ ID_{50} &= 207 \times 1.29 = 267 \text{ mg/man} \\ TD_{50} &= 63 \times 1.29 = 63 \text{ mg/man}\end{aligned}$$

Personnel exposed to less than 25 mg-min/ m^3 had no loss of duty time (if visual capabilities were required for job performance, then 1 mg-min/ m^3 was the threshold). Personnel exposed to 100 mg-min/ m^3 were not available for duty for four days. Personnel exposed up to 250 mg-min/ m^3 were not available for duty for 10 days.

To represent the regimen based on monoclonal antibody pretreatment, new critical toxicology values had to be

calculated. Initially, a no incapacitation value (no loss of duty time) ICT_0 and the TCT_{50} were identified as $1 \times LCT_{50}$ or 50 mg-min/m^3 . The new LCT_0 value (100% survival) was identified as $5 \times LCT_{50}$ or 250 mg-min/m^3 . Further, since the soldier was identified as being symptom-free at $1 \times LCT_{50}$ using this regimen, a TCT_{50} eye value of 50 mg-min/m^3 and the ECT_{50} eye value of 50 mg-min/m^3 were assumed. The probit slope of 0.1125 was also assumed to be unchanged.

To calculate the LCT_{50} value, a distance of 2.27 probits was used from the LCT_0 value of 250 mg-min/m^3 , resulting in a value of 450 mg-min/m^3 .

To calculate the ICT_{50} value, a distance of 2.27 probits was used from the ICT_0 value of 50 mg-min/m^3 , resulting in a value of 90 mg-min/m^3 .

To approximate the percutaneous liquid and vapor toxicology values, the ratio of the median response respiratory values for therapy versus without therapy was calculated. The resulting ratios were 9 for lethal effects, 2.57 for incapacitation effects, and 2.57 for threshold effects. These ratios were used to calculate new percutaneous values as follows:

$$\begin{aligned}\text{Vapor } LCT_{50} &= 2900 \times 9 = 26000 \text{ mg-min/m}^3 \\ ICT_{50} &= 1900 \times 2.57 = 4883 \text{ mg-min/m}^3 \\ TCT_{50} &= 200 \times 2.57 = 514 \text{ mg-min/m}^3\end{aligned}$$

$$\begin{aligned}\text{Liquid } LD_{50} &= 350 \times 9 = 3150 \text{ mg/man} \\ ID_{50} &= 207 \times 2.57 = 532 \text{ mg/man} \\ TD_{50} &= 63 \times 2.57 = 162 \text{ mg/man}\end{aligned}$$

Personnel exposed to $< 50 \text{ mg-min/m}^3$ had no loss of duty time (if visual capabilities were required for job performance, then 50 mg-min/m^3 was the threshold). Personnel exposed to 50 mg-min/m^3 were not available for duty for four days.

As additional information became available, refinements in the methodology used to calculate return-to-duty time were adopted and were, in fact, used in this study. The refinements were based on the development of a representation of the impact of convulsions. Personnel who convulse will take a much longer period of time to recover from the nerve agent exposure than those who do not. The probability of convulsing was found to be an exposure-related phenomena. The following table represents the return-to-duty profile for no therapy. Note that the Fraction column refers to the percent of incapacitated personnel in the particular dosage bin that would be returned to duty by the time indicated in the return-to-duty column. The effect of convulsing can be seen in the longer return-to-duty time exhibited for a given exposure. The following profile is valid for no therapy against a soman exposure.

<u>Return-to-duty days</u>	<u>Fraction %</u>	<u>Ratio of LD₅₀</u>
0	100	<0.1
2	100	0.1< >0.25
4	80	0.25< >0.4
10	50	0.4< >0.75
14	50	0.75< >1.0
	20	1.0< >2.0
21	20	0.25< >0.4
	50	0.4< >0.75
	50	0.75< >1.0
	80	1.0< >2.0
30	100	>2.0

The next profile is based on an exposure to soman with available therapy of atropine and 2-PAM

<u>Return-to-duty days</u>	<u>Fraction %</u>	<u>Ratio of LD₅₀</u>
0	100	<0.02
1	100	0.02< >0.2
2	100	0.2< >0.25
4	100	0.25< >0.8
7	100	0.8< >1.0
	75	1.0< >1.25
	60	1.25< >1.5
14	60	1.5< >1.75
	20	1.75< >3.5
21	25	1.0< >1.25
	40	1.25< >1.5
	40	1.5< >1.75
	80	1.75< >3.5
30	100	>3.5

The following profile reflects the return-to-duty profile when pyridostigmine pretreatment is combined with atropine, 2-PAM, and a hypothetical anticonvulsant therapy regimen.

<u>Return-to-duty days</u>	<u>Fraction %</u>	<u>Ratio of LD₅₀</u>
0	100	<0.02
1	100	0.02< >0.2
2	100	0.2< >0.4
4	100	0.4< >0.8
7	100	0.8< >1.0
	75	1.0< >1.25
	50	1.25< >1.5
14	50	1.5< >3.5
21	25	1.0< >1.25
	50	1.25< >1.5
	50	1.5< >3.5
	10	3.5< >5.0
30	90	3.5< >5.0
	100	>5.0

This last profile reflects the consequences of a soman exposure with available monoclonal antibody pretreatment.

<u>Return-to-duty days</u>	<u>Fraction %</u>	<u>Ratio of LD₅₀</u>
0	100	<0.02
1	20	0.02< >2.0
2	30	0.02< >2.0
3	25	0.02< >2.0
4	25	0.02< >2.0
10	100	2.0< >5.0
21	100	5.0< >9.0
30	100	>9.0

APPENDIX D
Algorithm for Estimating Metabolic Rates Expected
with Different Job Combinations

Originally, the jobs required to accomplish the firing mission in the M109A2 Artillery Battery were categorized according to the intensity of the work required: light, medium and heavy. Table D-1 shows the breakdown of jobs according to work intensity and corresponding metabolic rates.<*>

Table D-1. Metabolic Rates per Job Category.		
Job Category	Work Intensity	Metabolic Rate (Watts)
Drivers	Light	125
Gunners	Medium	250
Gun Section Chiefs	Medium	250
Loaders	Heavy	425

The metabolic rates shown in Table D-1 reflect the work intensity required by personnel performing these task in concert, that is without having to improvise to make up for personnel casualties. In the event that certain jobs cannot be filled, alternate pathways exist to accomplish the firing mission. Figure D-1 shows these alternate pathways as modeled within AURA.

100% → Gun Section Chief - Gunner - Loader

70% → Gun Section Chief - Gunner

50% → Gun Section Chief - Loader

30% → Loader - Driver

Figure D-1. Alternate Pathways for Firing Mission in AURA.

During the course of the study, an algorithm was developed

to estimate the work intensity required by personnel "filling in" for personnel who had become unit casualties. Assume, for example, that one of the Loaders has become a casualty and that the AURA model has decided that the most efficient way of completing the mission is to have the Gunner and Gun Section Chief perform the mission. According to the definition of the unit and its structure, the maximum contribution of this gun section to the overall effectiveness of the mission is 70%. But this does not account for the increased work intensity required for the Gunner and Gun Section Chief to perform both their original jobs and that of the missing Loader.

The following algorithm was used to estimate the work intensity required in different pathways:

$$WI_{New} = \frac{1}{2}(MR_{New Job} - 105) E_p + (MR_{Initial Job} - 105) E_p + 105$$

where,

$WI_{New} \Rightarrow$ Work Intensity required for new job,

$MR_{New Job} \Rightarrow$ Metabolic Rate required for
job to be assumed ,

$E_p \Rightarrow$ Maximum Effectiveness possible for this pathway,

$MR_{Initial Job} \Rightarrow$ Metabolic Rate required by initial job,

105 \Rightarrow Resting Metabolic Rate.

APPENDIX E
Modeling of Work Disciplines and Their Effects in AURA

The BRL implementation of Goldman-Givoni model uses the equilibrium core temperature to produce a probability of casualty to be used within the AURA model. The BRL implementation of Goldman-Givoni makes no attempt to determine an individual's core temperature at any given time. In order to model the effects of work/rest cycles and the new work discipline considered, modifications to the Goldman-Givoni model were made at SAIC and then, subsequently transformed for use in AURA. These modifications included producing a profile of core temperature over time for the conditions specified.

In order to model work/rest within AURA, this core temperature profile was examined and from it the highest core temperature seen over the course of the day was determined. The highest core temperature value was then fed back into Goldman-Givoni as the desired equilibrium core temperature for the given set of conditions. Goldman-Givoni then produced the metabolic rate which would result in this equilibrium core temperature for use in AURA. In this way, we were able to model work/rest cycles in AURA without having to keep track of individual's core temperatures within the AURA model.

In addition to the effect work/rest cycles have on core temperature, it was also necessary to include the impact of not being available to continuously perform the required firing mission. In the conditions examined, work/rest cycles of 45 minutes of work and 15 minutes of rest were prescribed when in BDUs. This results in a performance degradation factor of 75% (25% degradation in performance). When operating in BDO4, the required work/rest ratio is 20 minutes of work and 40 minutes of rest, resulting in a performance factor of 34%. These values were input to AURA via AURA's TIME-DEPENDENT DEGRADATION option.

The modeling of the new work discipline was accomplished by using a similar approach. The concept behind this discipline was to have troops pace themselves so as not to have their core temperatures exceed a specified temperature limit, for example 38.5°C. 38.5°C was then input to Goldman-Givoni as the desired equilibrium core temperature for each set of meteorological conditions and acclimatization/dehydration combination. Goldman-Givoni then predicted the metabolic rate required to achieve this equilibrium core temperature. Thus, a new metabolic rate was produced for each time period and each acclimatization/dehydration case. This metabolic rate was then input to AURA. This enabled AURA to determine the appropriate values for probability of casualty and to determine the appropriate level of personnel losses.

Finally, the impact of pacing unit operations in this manner was included in AURA by using AURA's TIME-DEPENDENT DEGRADATION option. The values used in this section were a result of using the following algorithm,

If

$$MR_{Limited} \geq MR_{Initial} \text{ then } PF = 1$$

Else if

$$MR_{Limited} \leq 105, \text{ then } PF = 0,$$

Else

$$PF = \frac{MR_{Limited} - 105}{MR_{Initial} - 105}.$$

Where,

$MR_{Limited}$ = Metabolic rate limited by maintaining core temperature at/below specified value.

$MR_{Initial}$ = Metabolic rate initially required for job.

PF = Performance Factor as used within AURA.

105 = Resting metabolic rate.

for each of the required jobs for each time period (ie. set of met conditions) during the day. Tables E-1 through E-4 list the performance factors used for the 38.5°C case for the different clothing considered and the different acclimatization/dehydration combinations examined. Tables E-3 through E-12 list the same information for the 39°C case.

Table E-1. Performance Degradation Factors for Metabolic Limit Case of 38.5°C, Case 1

		Case 1: Unacclimatized Troops 5% Dehydration Clothing: BDUs				
Limited Metabolic Rates:	JOBS	PERFORMANCE FACTORS TIME OF DAY				
		0000-0700	0700-1100	1100-1500	1500-1900	1900-2300 2300-2400
	INITIAL MET. RATES	134	121	100	110	119 134
	Drivers ⁴	132.75	1.00	0.58	0.00	0.18 0.50 1.00
	Gunners ¹	250.00	0.20	0.11	0.00	0.03 0.10 0.20
	Gunners ²	313.50	0.14	0.08	0.00	0.02 0.07 0.14
	GSCs ¹	250.00	0.20	0.11	0.00	0.03 0.10 0.20
	GSCs ²	313.50	0.14	0.08	0.00	0.02 0.07 0.14
	GSCs ³	213.75	0.27	0.15	0.00	0.05 0.13 0.27
	Loaders ¹	425.00	0.09	0.05	0.00	0.02 0.04 0.09
	Loaders ²	301.25	0.15	0.08	0.00	0.03 0.07 0.15
	Loaders ³	222.75	0.25	0.14	0.00	0.04 0.12 0.25

1. Jobs used in pathway with a maximum of 100% effectiveness possible.
2. Jobs used in pathway with a maximum of 70% effectiveness possible.
3. Jobs used in pathway with a maximum of 50% effectiveness possible.
4. Jobs used in pathway with a maximum of 30% effectiveness possible.

Table E-2. Performance Degradation Factors for Metabolic Limit Case of 38.5°C, Case 2

Case 2: Unacclimatized Troops
5% Dehydration
Clothing: BDO4

JOBS	INITIAL MET. RATES	PERFORMANCE FACTORS TIME OF DAY				
		0000-0700	0700-1100	1100-1500	1500-1900	1900-2300
Limited Metabolic Rates:		100	93	74	91	88
						100
Drivers ⁴	132.75	0.00	0.00	0.00	0.00	0.00
Gunners ¹	250.00	0.00	0.00	0.00	0.00	0.00
Gunners ²	313.50	0.00	0.00	0.00	0.00	0.00
GSCs ¹	250.00	0.00	0.00	0.00	0.00	0.00
GSCs ²	313.50	0.00	0.00	0.00	0.00	0.00
GSCs ³	213.75	0.00	0.00	0.00	0.00	0.00
Loaders ¹	425.00	0.00	0.00	0.00	0.00	0.00
Loaders ²	301.25	0.00	0.00	0.00	0.00	0.00
Loaders ³	222.75	0.00	0.00	0.00	0.00	0.00

1. Jobs used in pathway with a maximum of 100% effectiveness possible.
2. Jobs used in pathway with a maximum of 70% effectiveness possible.
3. Jobs used in pathway with a maximum of 50% effectiveness possible.
4. Jobs used in pathway with a maximum of 30% effectiveness possible.

Table E-3. Performance Degradation Factors for Metabolic Limit Case of 38.5°C, Case 3

Case 3: Fully Acclimatized Troops
2% Dehydration
Clothing: BDUs

JOBS	INITIAL MET. RATES	PERFORMANCE FACTORS TIME OF DAY					
		0000-0700	0700-1100	1100-1500	1500-1900	1900-2300	2300-2400
Limited Metabolic Rates:		347	338	324	335	328	347
Drivers ⁴	132.75	1.00	1.00	1.00	1.00	1.00	1.00
Gunners ¹	250.00	1.00	1.00	1.00	1.00	1.00	0.00
Gunners ²	313.50	1.00	1.00	1.00	1.00	1.00	0.00
GSCs ¹	250.00	1.00	1.00	1.00	1.00	1.00	0.00
GSCs ²	313.50	1.00	1.00	1.00	1.00	1.00	0.00
GSCs ³	213.75	1.00	1.00	1.00	1.00	1.00	0.00
Loaders ¹	425.00	0.76	0.73	0.68	0.72	0.70	0.76
Loaders ²	301.25	1.00	1.00	1.00	1.00	1.00	0.00
Loaders ³	222.75	1.00	1.00	1.00	1.00	1.00	0.00

1. Jobs used in pathway with a maximum of 100% effectiveness possible.
2. Jobs used in pathway with a maximum of 70% effectiveness possible.
3. Jobs used in pathway with a maximum of 50% effectiveness possible.
4. Jobs used in pathway with a maximum of 30% effectiveness possible.

Table E-4. Performance Degradation Factors for Metabolic Limit Case of 38.5°C, Case 4

Case 4: Fully Acclimatized Troops
2% Dehydration
Clothing: BDO4

JOBS	INITIAL MET. RATES	PERFORMANCE FACTORS TIME OF DAY						
		0000-0700	0700-1100	1100-1500	1500-1900	1900-2300	2300-2400	
Limited Metabolic Rates:		264	267	269	278	250	264	
Drivers ⁴	132.75	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gunners ¹	250.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gunners ²	313.50	0.76	0.78	0.79	0.83	0.70	0.76	0.76
GSCs ¹	250.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
GSCs ²	313.50	0.76	0.78	0.79	0.83	0.70	0.76	0.76
GSCs ³	213.75	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Loaders ¹	425.00	0.50	0.51	0.51	0.54	0.45	0.50	0.50
Loaders ²	301.25	0.81	0.83	0.84	0.88	0.74	0.81	0.81
Loaders ³	222.75	1.00	1.00	1.00	1.00	1.00	1.00	1.00

1. Jobs used in pathway with a maximum of 100% effectiveness possible.
2. Jobs used in pathway with a maximum of 70% effectiveness possible.
3. Jobs used in pathway with a maximum of 50% effectiveness possible.
4. Jobs used in pathway with a maximum of 30% effectiveness possible.

Table E-5. Performance Degradation Factors for Metabolic Limit Case of 39°C, Case 1

Case 1: Unacclimatized Troops
5% Dehydration
Clothing: BDUs

Limited Metabolic Rates:	PERFORMANCE FACTORS TIME OF DAY				
	0000-0700	0700-1100	1100-1500	1500-1900	1900-2300 2300-2400
	211	198	178	188	195 211
JOB	INITIAL MET. RATES				
Drivers ⁴	132.75	1.00	1.00	1.00	1.00
Gunners ¹	250.00	0.73	0.50	0.57	0.73
Gunners ²	313.50	0.51	0.35	0.40	0.51
GSCs ¹	250.00	0.73	0.50	0.57	0.73
GSCs ²	313.50	0.51	0.35	0.40	0.51
GSCs ³	213.75	0.97	0.67	0.76	0.97
Loaders ¹	425.00	0.33	0.23	0.26	0.33
Loaders ²	301.25	0.54	0.37	0.42	0.54
Loaders ³	222.75	0.90	0.62	0.70	0.90

1. Jobs used in pathway with a maximum of 100% effectiveness possible.
2. Jobs used in pathway with a maximum of 70% effectiveness possible.
3. Jobs used in pathway with a maximum of 50% effectiveness possible.
4. Jobs used in pathway with a maximum of 30% effectiveness possible.

Table E-6. Performance Degradation Factors for Metabolic Limit Case of 39°C, Case 2

Case 2: Unacclimatized Troops
5% Dehydration
Clothing: MOPPl (overgarment only)

Limited Metabolic Rates:	PERFORMANCE FACTORS TIME OF DAY				
	0000-0700	0700-1100	1100-1500	1500-1900	1900-2300 2300-2400
	180	172	163	171	169 180
JOBS INITIAL MET. RATES					
Drivers ⁴	132.75	1.00	1.00	1.00	1.00 1.00
Gunners ¹	250.00	0.52	0.40	0.46	0.44 0.52
Gunners ²	313.50	0.36	0.28	0.32	0.31 0.36
GSCs ¹	250.00	0.52	0.40	0.46	0.44 0.52
GSCs ²	313.50	0.36	0.28	0.32	0.31 0.36
GSCs ³	213.75	0.69	0.53	0.61	0.59 0.69
Loaders ¹	425.00	0.23	0.18	0.21	0.20 0.23
Loaders ²	301.25	0.38	0.30	0.34	0.33 0.38
Loaders ³	222.75	0.64	0.49	0.56	0.54 0.64

1. Jobs used in pathway with a maximum of 100% effectiveness possible.
2. Jobs used in pathway with a maximum of 70% effectiveness possible.
3. Jobs used in pathway with a maximum of 50% effectiveness possible.
4. Jobs used in pathway with a maximum of 30% effectiveness possible.

Table E-7. Performance Degradation Factors for Metabolic Limit Case of 39°C, Case 3

Case 3: Unacclimatized Troops
5% Dehydration
Clothing: BDU + BDO

JOBS	INITIAL MET. RATES	PERFORMANCE FACTORS TIME OF DAY				
		0000-0700	0700-1100	1100-1500	1500-1900	1900-2300
Limited Metabolic Rates:		146	134	120	129	132
						146
Drivers ⁴	132.75	1.00	1.00	0.54	0.86	0.97
Gunners ¹	250.00	0.28	0.20	0.10	0.17	0.19
Gunners ²	313.50	0.20	0.14	0.07	0.12	0.13
GSCs ¹	250.00	0.28	0.20	0.10	0.17	0.19
GSCs ²	313.50	0.20	0.14	0.07	0.12	0.13
GSCs ³	213.75	0.38	0.27	0.14	0.22	0.25
Loaders ¹	425.00	0.13	0.09	0.05	0.08	0.08
Loaders ²	301.25	0.21	0.15	0.08	0.12	0.14
Loaders ³	222.75	0.35	0.25	0.13	0.20	0.23
						1.00
						0.28
						0.20
						0.28
						0.20
						0.38
						0.13
						0.21
						0.35

1. Jobs used in pathway with a maximum of 100% effectiveness possible.
2. Jobs used in pathway with a maximum of 70% effectiveness possible.
3. Jobs used in pathway with a maximum of 50% effectiveness possible.
4. Jobs used in pathway with a maximum of 30% effectiveness possible.

Table E-8. Performance Degradation Factors for Metabolic Limit Case of 39°C, Case 4

Case 4: Unacclimatized Troops
5% Dehydration
Clothing: BDO4

JOBS	INITIAL MET. RATES	PERFORMANCE FACTORS TIME OF DAY				
		0000-0700	0700-1100	1100-1500	1500-1900	1900-2300 2300-2400
Limited Metabolic Rates:		169	162	153	162	155 169
Drivers ⁴	132.75	1.00	1.00	1.00	1.00	1.00
Gunners ¹	250.00	0.44	0.39	0.33	0.39	0.34
Gunners ²	313.50	0.31	0.27	0.23	0.27	0.24
GSCs ¹	250.00	0.44	0.39	0.33	0.39	0.34
GSCs ²	313.50	0.31	0.27	0.23	0.27	0.24
GSCs ³	213.75	0.59	0.52	0.44	0.52	0.46
Loaders ¹	425.00	0.20	0.18	0.15	0.18	0.16
Loaders ²	301.25	0.33	0.29	0.24	0.29	0.25
Loaders ³	222.75	0.54	0.48	0.41	0.48	0.42
						1.00 0.44 0.31 0.44 0.31 0.59 0.20 0.33 0.54

1. Jobs used in pathway with a maximum of 100% effectiveness possible.
2. Jobs used in pathway with a maximum of 70% effectiveness possible.
3. Jobs used in pathway with a maximum of 50% effectiveness possible.
4. Jobs used in pathway with a maximum of 30% effectiveness possible.

Table E-9. Performance Degradation Factors for Metabolic Limit Case of 39°C, Case 5

Case 5: Fully Aacclimatized Troops
2% Dehydration
Clothing: BDUs

JOBS	INITIAL MET. RATES	PERFORMANCE FACTORS TIME OF DAY				
		0000-0700	0700-1100	1100-1500	1500-1900	1900-2300
Limited Metabolic Rates:		445	438	428	441	424
						445
Drivers ⁴	132.75	1.00	1.00	1.00	1.00	1.00
Gunners ¹	250.00	1.00	1.00	1.00	1.00	1.00
Gunners ²	313.50	1.00	1.00	1.00	1.00	1.00
GSCs ¹	250.00	1.00	1.00	1.00	1.00	1.00
GSCs ²	313.50	1.00	1.00	1.00	1.00	1.00
GSCs ³	213.75	1.00	1.00	1.00	1.00	1.00
Loaders ¹	425.00	1.00	1.00	1.00	1.00	1.00
Loaders ²	301.25	1.00	1.00	1.00	1.00	1.00
Loaders ³	222.75	1.00	1.00	1.00	1.00	1.00

1. Jobs used in pathway with a maximum of 100% effectiveness possible.
2. Jobs used in pathway with a maximum of 70% effectiveness possible.
3. Jobs used in pathway with a maximum of 50% effectiveness possible.
4. Jobs used in pathway with a maximum of 30% effectiveness possible.

Table E-10. Performance Degradation Factors for Metabolic Limit Case of 39°C, Case 6

Case 6: Fully Acclimatized Troops
2% Dehydration
Clothing: MOPP1 (overgarment only)

			PERFORMANCE FACTORS TIME OF DAY					
			0000-0700	0700-1100	1100-1500	1500-1900	1900-2300	2300-2400
Limited Metabolic Rates:			367	368	372	382	351	367
JOBS			INITIAL MET. RATES					
Drivers ⁴		132.75	1.00	1.00	1.00	1.00	1.00	1.00
Gunners ¹		250.00	1.00	1.00	1.00	1.00	1.00	1.00
Gunners ²		313.50	1.00	1.00	1.00	1.00	1.00	1.00
GSCs ¹		250.00	1.00	1.00	1.00	1.00	1.00	1.00
GSCs ²		313.50	1.00	1.00	1.00	1.00	1.00	1.00
GSCs ³		213.75	1.00	1.00	1.00	1.00	1.00	1.00
Loaders ¹		425.00	0.82	0.82	0.83	0.87	0.77	0.82
Loaders ²		301.25	1.00	1.00	1.00	1.00	1.00	1.00
Loaders ³		222.75	1.00	1.00	1.00	1.00	1.00	1.00

1. Jobs used in pathway with a maximum of 100% effectiveness possible.
2. Jobs used in pathway with a maximum of 70% effectiveness possible.
3. Jobs used in pathway with a maximum of 50% effectiveness possible.
4. Jobs used in pathway with a maximum of 30% effectiveness possible.

Table E-11. Performance Degradation Factors for Metabolic Limit Case of 39°C, Case 7

Case 7: Fully Acclimatized Troops
2% Dehydration
Clothing: BDU + BDO

JOBS	INITIAL MET. RATES	PERFORMANCE FACTORS TIME OF DAY				
		0000-0700	0700-1100	1100-1500	1500-1900	1900-2300
Limited Metabolic Rates:		279	273	266	277	263
						279
Drivers ⁴	132.75	1.00	1.00	1.00	1.00	1.00
Gunners ¹	250.00	1.00	1.00	1.00	1.00	1.00
Gunners ²	313.50	0.83	0.81	0.77	0.82	0.76
GSCs ¹	250.00	1.00	1.00	1.00	1.00	1.00
GSCs ²	313.50	0.83	0.81	0.77	0.82	0.76
GSCs ³	213.75	1.00	1.00	1.00	1.00	1.00
Loaders ¹	425.00	0.54	0.53	0.50	0.54	0.49
Loaders ²	301.25	0.89	0.86	0.82	0.88	0.81
Loaders ³	222.75	1.00	1.00	1.00	1.00	1.00

1. Jobs used in pathway with a maximum of 100% effectiveness possible.
2. Jobs used in pathway with a maximum of 70% effectiveness possible.
3. Jobs used in pathway with a maximum of 50% effectiveness possible.
4. Jobs used in pathway with a maximum of 30% effectiveness possible.

Table E-12. Performance Degradation Factors for Metabolic Limit Case of 39°C, Case 8

Case 8: Fully Acclimatized Troops
2% Dehydration
Clothing: BDO4

JOBS	INITIAL MET. RATES	PERFORMANCE FACTORS TIME OF DAY					
		0000-0700	0700-1100	1100-1500	1500-1900	1900-2300	2300-2400
Limited Metabolic Rates:	340	345	351	362	324	340	
Drivers ⁴	132.75	1.00	1.00	1.00	1.00	1.00	1.00
Gunners ¹	250.00	1.00	1.00	1.00	1.00	1.00	1.00
Gunners ²	313.50	1.00	1.00	1.00	1.00	1.00	1.00
GSCs ¹	250.00	1.00	1.00	1.00	1.00	1.00	1.00
GSCs ²	313.50	1.00	1.00	1.00	1.00	1.00	1.00
GSCs ³	213.75	1.00	1.00	1.00	1.00	1.00	1.00
Loaders ¹	425.00	0.73	0.75	0.77	0.80	0.68	0.73
Loaders ²	301.25	1.00	1.00	1.00	1.00	1.00	1.00
Loaders ³	222.75	1.00	1.00	1.00	1.00	1.00	1.00

1. Jobs used in pathway with a maximum of 100% effectiveness possible.
2. Jobs used in pathway with a maximum of 70% effectiveness possible.
3. Jobs used in pathway with a maximum of 50% effectiveness possible.
4. Jobs used in pathway with a maximum of 30% effectiveness possible.

APPENDIX F
AURA Unit Input File for the M109 Artillery Unit

REPERTOIRE

ASSETS

SP FA AUTO MECH, PERSONNEL, MECH, CREW
FA WEAPONS MECH, PERSONNEL, MECH, CREW
SP FA SYSTEM MECH, PERSONNEL, MECH, CREW
SVC TM CHIEF, PERSONNEL, MECH, CREW
AUTHORITY, PERSONNEL
PLT LDR, PERSONNEL
FA FD CREW MANUAL, PERSONNEL
FDO MANUAL, PERSONNEL
FA FD CREW COMPTR, PERSONNEL
FDO CALCULATOR, PERSONNEL
PLT DRIVERS, PLT CREW, PERSONNEL
PLT SGT, PLT CREW, PERSONNEL
M577 DRIVER, PERSONNEL
FA FD CREW, FDC CREW, PERSONNEL
CHF FD COMPUTER, FDC CREW, PERSONNEL
FDO, FDC CREW, PERSONNEL
#DRIVER, PERSONNEL
BTRY PERSONNEL, PERSONNEL
NBC NCO, PERSONNEL
1ST SGT, PERSONNEL
BTRY CO, PERSONNEL
#LOADER, PERSONNEL
#GUNNER, PERSONNEL
#GUN SECT CHF, PERSONNEL
#GUN SECT CHF1, PERSONNEL
#GUN SECT CHF2, PERSONNEL
FDC RADIO, SRADIO, EQP
PLT VRC-46, SRADIO, EQP
PLT PRC-68, SRADIO, EQP
FDC PHONE, SRADIO, EQP
FDC PRC-68, SRADIO, EQP
FDC VRC-46, SRADIO, EQP
FDC COMMO, SRADIO, EQP
BTRY GRC-160, SRADIO, EQP
BTRY VRC-46, SRADIO, EQP
BTRY PRC-68, SRADIO, EQP
BTRY PHONE, SRADIO, EQP
M577A1, EQP
M109, EQP
TRUCK 2-1/2, EQP
AIMING CIRCLE, AIMING DEVICE, EQP
LAYING GUN, GUNELEC, EQP
PLOTING EQP, GUNELEC, EQP
BCS, TDS, EQP
FDC COMPUTER, TDS, EQP
AIMING STAKE, AIMING DEVICE, EQP
COLLIMATOR, EQP
AIM GUNS, GUNELEC, EQP
GDU, TDS, EQP
GS1, GUN SECTION CHFS, PERSONNEL
GS2, GUN SECTION CHFS, PERSONNEL
GS3, GUN SECTION CHFS, PERSONNEL
GS4, GUN SECTION CHFS, PERSONNEL
GS5, GUN SECTION CHFS, PERSONNEL
GS6, GUN SECTION CHFS, PERSONNEL
GS7, GUN SECTION CHFS, PERSONNEL
GS8, GUN SECTION CHFS, PERSONNEL
GN1, GUNNERS, PERSONNEL
GN2, GUNNERS, PERSONNEL
GN3, GUNNERS, PERSONNEL
GN4, GUNNERS, PERSONNEL
GN5, GUNNERS, PERSONNEL

GN6,GUNNERS,PERSONNEL
 GN7,GUNNERS,PERSONNEL
 GN8,GUNNERS,PERSONNEL
 LD1,LOADERS,PERSONNEL
 LD2,LOADERS,PERSONNEL
 LD3,LOADERS,PERSONNEL
 LD4,LOADERS,PERSONNEL
 LD5,LOADERS,PERSONNEL
 LD6,LOADERS,PERSONNEL
 LD7,LOADERS,PERSONNEL
 LD8,LOADERS,PERSONNEL
 DR1,DRIVERS,PERSONNEL
 DR2,DRIVERS,PERSONNEL
 DR3,DRIVERS,PERSONNEL
 DR4,DRIVERS,PERSONNEL
 DR5,DRIVERS,PERSONNEL
 DR6,DRIVERS,PERSONNEL
 DR7,DRIVERS,PERSONNEL
 DR8,DRIVERS,PERSONNEL

WEAPONS

TOXWPN,TOXIC
 WPN22,CONVENTIONAL
 WPN22M,CONVENTIONAL
 WPN52,CONVENTIONAL
 WPN250,CONVENTIONAL
 WPN100,CONVENTIONAL

END

DELIVERY ERROR

WPN22,115.,46.,28.,11.,0.
 WPN52,129.,52.,72.,12.,0.
 WPN22M,102.,41.,70.,90.,0.

END

CEP ERROR

WPN250,182.9,15.91,0. # 4000 FT.
 WPN100,182.9,15.91,0.

END

DEPLOYMENT

NO COMMO	, 0.00,	0.00,	-1.00,	1,	1,	1,	1,	1,	2
SP FA AUTO MECH	, 1295.57,	2830.92,	4.00,	1,	1,	1,	1,	1,	2
FA WEAPONS MECH	, 1319.48,	2842.43,	2.00,	1,	1,	1,	1,	1,	2
SVC TM CHIEF	, 1314.00,	2843.00,	1.00,	1,	1,	1,	1,	1,	2
MED	, 1314.00,	2843.00,	2.00,	1,	1,	1,	1,	1,	2
LIGHT	, 1314.00,	2843.00,	2.00,	1,	1,	1,	1,	1,	2
SP FA SYSTEM MECH	, 1295.57,	2830.92,	4.00,	1,	1,	1,	1,	1,	2
M109	, 93.15,	4383.56,	1.00,	2,	1,	1,	1,	1,	2
TRUCK 2-1/2	, 95.15,	4783.56,	1.00,	1,	1,	1,	1,	1,	2
GDU	, 93.15,	4383.56,	1.00,	1,	1,	1,	1,	1,	2
AIM GUNS	, 93.15,	4383.56,	1.00,	1,	1,	1,	1,	1,	2
COLLIMATOR	, 93.15,	4383.56,	1.00,	1,	1,	1,	1,	1,	2
LAYING GUN	, 93.15,	4383.56,	1.00,	1,	1,	1,	1,	1,	2
AIMING CIRCLE	, 93.15,	4383.56,	2.00,	1,	1,	1,	1,	1,	2
AIMING STAKE	, 93.15,	4383.56,	1.00,	1,	1,	1,	1,	1,	2
#GUNNER	, 93.15,	4383.56,	-1.00,	1,	1,	4,	4,	1,	2
GN1	, 93.15,	4383.56,	1.00,	1,	1,	4,	4,	1,	2
GUN1	, 93.15,	4383.56,	-1.00,	1,	1,	4,	4,	1,	2
DR1	, 93.15,	4383.56,	1.00,	1,	1,	6,	4,	1,	2
#GUNNER1	, 93.15,	4383.56,	-1.00,	1,	1,	4,	4,	1,	2
GUN11	, 93.15,	4383.56,	-1.00,	1,	1,	4,	4,	1,	2
#LOADER	, 93.15,	4383.56,	-1.00,	1,	1,	3,	4,	1,	2
LD1	, 93.15,	4383.56,	1.00,	1,	1,	3,	4,	1,	2
LOD1	, 93.15,	4383.56,	-1.00,	1,	1,	3,	4,	1,	2
#LOADER1	, 93.15,	4383.56,	-1.00,	1,	1,	3,	4,	1,	2
LOD11	, 93.15,	4383.56,	-1.00,	1,	1,	3,	4,	1,	2
#LOADER2	, 93.15,	4383.56,	-1.00,	1,	1,	3,	4,	1,	2

LOD21	,	93.15,	4383.56,	-1.00,	1,	1,	3,	4,	1,	2
#GUN SECT CHF	,	93.15,	4383.56,	-1.00,	1,	1,	2,	4,	1,	2
GS1	,	93.15,	4383.56,	1.00,	1,	1,	2,	4,	1,	2
GSC1	,	93.15,	4383.56,	-1.00,	1,	1,	2,	4,	1,	2
#GUN SECT CHF1	,	93.15,	4383.56,	-1.00,	1,	1,	2,	4,	1,	2
GSC11	,	93.15,	4383.56,	-1.00,	1,	1,	2,	4,	1,	2
#GUN SECT CHF2	,	93.15,	4383.56,	-1.00,	1,	1,	2,	4,	1,	2
GSC21	,	93.15,	4383.56,	-1.00,	1,	1,	2,	4,	1,	2
M109	,	193.15,	4483.56,	1.00,	2,	1,	1,	1,	1,	2
#GUN SECT CHF	,	193.15,	4483.56,	-1.00,	1,	1,	2,	4,	1,	2
GS2	,	193.15,	4483.56,	1.00,	1,	1,	2,	4,	1,	2
GSC2	,	193.15,	4483.56,	-1.00,	1,	1,	2,	4,	1,	2
#GUN SECT CHF1	,	193.15,	4483.56,	-1.00,	1,	1,	2,	4,	1,	2
GSC12	,	193.15,	4483.56,	-1.00,	1,	1,	2,	4,	1,	2
#GUN SECT CHF2	,	193.15,	4483.56,	-1.00,	1,	1,	2,	4,	1,	2
GSC22	,	193.15,	4483.56,	-1.00,	1,	1,	2,	4,	1,	2
TRUCK 2-1/2	,	595.15,	4483.56,	1.00,	1,	1,	1,	1,	1,	2
GDU	,	193.15,	4483.56,	1.00,	1,	1,	1,	1,	1,	2
AIM GUNS	,	193.15,	4483.56,	1.00,	1,	1,	1,	1,	1,	2
COLLIMATOR	,	193.15,	4483.56,	1.00,	1,	1,	1,	1,	1,	2
LAYING GUN	,	193.15,	4483.56,	1.00,	1,	1,	1,	1,	1,	2
AIMING STAKE	,	193.15,	4483.56,	1.00,	1,	1,	1,	1,	1,	2
AIMING CIRCLE	,	193.15,	4483.56,	2.00,	1,	1,	1,	1,	1,	2
DR2	,	193.15,	4483.56,	1.00,	1,	1,	6,	4,	1,	2
#GUNNER	,	193.15,	4483.56,	-1.00,	1,	1,	4,	4,	1,	2
GN2	,	193.15,	4483.56,	1.00,	1,	1,	4,	4,	1,	2
GUN2	,	193.15,	4483.56,	-1.00,	1,	1,	4,	4,	1,	2
#GUNNER1	,	193.15,	4483.56,	-1.00,	1,	1,	4,	4,	1,	2
GUN12	,	193.15,	4483.56,	-1.00,	1,	1,	4,	4,	1,	2
#LOADER	,	193.15,	4483.56,	-1.00,	1,	1,	3,	4,	1,	2
LD2	,	193.15,	4483.56,	1.00,	1,	1,	3,	4,	1,	2
LOD2	,	193.15,	4483.56,	-1.00,	1,	1,	3,	4,	1,	2
#LOADER1	,	193.15,	4483.56,	-1.00,	1,	1,	3,	4,	1,	2
LOD12	,	193.15,	4483.56,	-1.00,	1,	1,	3,	4,	1,	2
#LOADER2	,	193.15,	4483.56,	-1.00,	1,	1,	3,	4,	1,	2
LOD22	,	193.15,	4483.56,	-1.00,	1,	1,	3,	4,	1,	2
M109	,	293.15,	4383.56,	1.00,	2,	1,	1,	1,	1,	2
#GUN SECT CHF	,	293.15,	4383.56,	-1.00,	1,	1,	2,	4,	1,	2
GS3	,	293.15,	4383.56,	1.00,	1,	1,	2,	4,	1,	2
GSC3	,	293.15,	4383.56,	-1.00,	1,	1,	2,	4,	1,	2
#GUN SECT CHF1	,	293.15,	4383.56,	-1.00,	1,	1,	2,	4,	1,	2
GSC13	,	293.15,	4383.56,	-1.00,	1,	1,	2,	4,	1,	2
#GUN SECT CHF2	,	293.15,	4383.56,	-1.00,	1,	1,	2,	4,	1,	2
GSC23	,	293.15,	4383.56,	-1.00,	1,	1,	2,	4,	1,	2
TRUCK 2-1/2	,	695.15,	4383.56,	1.00,	1,	1,	1,	1,	1,	2
GDU	,	293.15,	4383.56,	1.00,	1,	1,	1,	1,	1,	2
AIM GUNS	,	293.15,	4383.56,	1.00,	1,	1,	1,	1,	1,	2
COLLIMATOR	,	293.15,	4383.56,	1.00,	1,	1,	1,	1,	1,	2
LAYING GUN	,	293.15,	4383.56,	1.00,	1,	1,	1,	1,	1,	2
AIMING STAKE	,	293.15,	4383.56,	1.00,	1,	1,	1,	1,	1,	2
AIMING CIRCLE	,	293.15,	4383.56,	2.00,	1,	1,	1,	1,	1,	2
DR3	,	293.15,	4383.56,	1.00,	1,	1,	6,	4,	1,	2
#GUNNER	,	293.15,	4383.56,	-1.00,	1,	1,	4,	4,	1,	2
GN3	,	293.15,	4383.56,	1.00,	1,	1,	4,	4,	1,	2
GUN3	,	293.15,	4383.56,	-1.00,	1,	1,	4,	4,	1,	2
#GUNNER1	,	293.15,	4383.56,	-1.00,	1,	1,	4,	4,	1,	2
GUN13	,	293.15,	4383.56,	-1.00,	1,	1,	4,	4,	1,	2
#LOADER	,	293.15,	4383.56,	-1.00,	1,	1,	3,	4,	1,	2
LD3	,	293.15,	4383.56,	1.00,	1,	1,	3,	4,	1,	2
LOD3	,	293.15,	4383.56,	-1.00,	1,	1,	3,	4,	1,	2
#LOADER1	,	293.15,	4383.56,	-1.00,	1,	1,	3,	4,	1,	2
LOD13	,	293.15,	4383.56,	-1.00,	1,	1,	3,	4,	1,	2
#LOADER2	,	293.15,	4383.56,	-1.00,	1,	1,	3,	4,	1,	2
LOD23	,	293.15,	4383.56,	-1.00,	1,	1,	3,	4,	1,	2

M109	, 393.15,	4333.56,	1.00,	2,	1,	1,	1,	1,	2
#GUN SECT CHF	, 393.15,	4333.56,	-1.00,	1,	1,	2,	4,	1,	2
GS4	, 393.15,	4333.56,	1.00,	1,	1,	2,	4,	1,	2
GSC4	, 393.15,	4333.56,	-1.00,	1,	1,	2,	4,	1,	2
#GUN SECT CHF1	, 393.15,	4333.56,	-1.00,	1,	1,	2,	4,	1,	2
GSC14	, 393.15,	4333.56,	-1.00,	1,	1,	2,	4,	1,	2
#GUN SECT CHF2	, 393.15,	4333.56,	-1.00,	1,	1,	2,	4,	1,	2
GSC24	, 393.15,	4333.56,	-1.00,	1,	1,	2,	4,	1,	2
TRUCK 2-1/2	, 795.15,	4333.56,	1.00,	1,	1,	1,	1,	1,	2
GDU	, 393.15,	4333.56,	1.00,	1,	1,	1,	1,	1,	2
AIM GUNS	, 393.15,	4333.56,	1.00,	1,	1,	1,	1,	1,	2
COLLIMATOR	, 393.15,	4333.56,	1.00,	1,	1,	1,	1,	1,	2
LAYING GUN	, 393.15,	4333.56,	1.00,	1,	1,	1,	1,	1,	2
AIMING STAKE	, 393.15,	4333.56,	1.00,	1,	1,	1,	1,	1,	2
AIMING CIRCLE	, 393.15,	4333.56,	2.00,	1,	1,	1,	1,	1,	2
DR4	, 393.15,	4333.56,	1.00,	1,	1,	6,	4,	1,	2
#GUNNER	, 393.15,	4333.56,	-1.00,	1,	1,	4,	4,	1,	2
GN4	, 393.15,	4333.56,	1.00,	1,	1,	4,	4,	1,	2
GUN4	, 393.15,	4333.56,	-1.00,	1,	1,	4,	4,	1,	2
#GUNNER1	, 393.15,	4333.56,	-1.00,	1,	1,	4,	4,	1,	2
GUN14	, 393.15,	4333.56,	-1.00,	1,	1,	4,	4,	1,	2
#LOADER1	, 393.15,	4333.56,	-1.00,	1,	1,	3,	4,	1,	2
LOD14	, 393.15,	4333.56,	-1.00,	1,	1,	3,	4,	1,	2
#LOADER2	, 393.15,	4333.56,	-1.00,	1,	1,	3,	4,	1,	2
LOD24	, 393.15,	4333.56,	-1.00,	1,	1,	3,	4,	1,	2
#LOADER	, 393.15,	4333.56,	-1.00,	1,	1,	3,	4,	1,	2
LD4	, 393.15,	4333.56,	1.00,	1,	1,	3,	4,	1,	2
LOD4	, 393.15,	4333.56,	-1.00,	1,	1,	3,	4,	1,	2
M109	, 1550.00,	4360.96,	1.00,	2,	1,	1,	1,	1,	2
#GUN SECT CHF	, 1552.00,	4360.96,	-1.00,	1,	1,	2,	4,	1,	2
GS5	, 1552.00,	4360.96,	1.00,	1,	1,	2,	4,	1,	2
GSC5	, 1552.00,	4360.96,	-1.00,	1,	1,	2,	4,	1,	2
#GUN SECT CHF1	, 1552.00,	4360.96,	-1.00,	1,	1,	2,	4,	1,	2
GSC15	, 1552.00,	4360.96,	-1.00,	1,	1,	2,	4,	1,	2
#GUN SECT CHF2	, 1552.00,	4360.96,	-1.00,	1,	1,	2,	4,	1,	2
GSC25	, 1552.00,	4360.96,	-1.00,	1,	1,	2,	4,	1,	2
TRUCK 2-1/2	, 1152.00,	4360.96,	1.00,	1,	1,	1,	1,	1,	2
GDU	, 1550.00,	4360.96,	1.00,	1,	1,	1,	1,	1,	2
AIM GUNS	, 1550.00,	4360.96,	1.00,	1,	1,	1,	1,	1,	2
COLLIMATOR	, 1550.00,	4360.96,	1.00,	1,	1,	1,	1,	1,	2
LAYING GUN	, 1550.00,	4360.96,	1.00,	1,	1,	1,	1,	1,	2
AIMING STAKE	, 1550.00,	4360.96,	2.00,	1,	1,	1,	1,	1,	2
AIMING CIRCLE	, 1550.00,	4360.96,	2.00,	1,	1,	1,	1,	1,	2
DR5	, 1550.00,	4360.96,	1.00,	1,	1,	6,	4,	1,	2
#GUNNER	, 1550.00,	4360.96,	-1.00,	1,	1,	4,	4,	1,	2
GN5	, 1550.00,	4360.96,	1.00,	1,	1,	4,	4,	1,	2
GUN5	, 1550.00,	4360.96,	-1.00,	1,	1,	4,	4,	1,	2
#GUNNER1	, 1550.00,	4360.96,	-1.00,	1,	1,	4,	4,	1,	2
GUN15	, 1550.00,	4360.96,	-1.00,	1,	1,	4,	4,	1,	2
#LOADER	, 1550.00,	4360.96,	-1.00,	1,	1,	3,	4,	1,	2
LD5	, 1550.00,	4360.96,	1.00,	1,	1,	3,	4,	1,	2
LOD5	, 1550.00,	4360.96,	-1.00,	1,	1,	3,	4,	1,	2
#LOADER1	, 1550.00,	4360.96,	-1.00,	1,	1,	3,	4,	1,	2
LOD15	, 1550.00,	4360.96,	-1.00,	1,	1,	3,	4,	1,	2
#LOADER2	, 1550.00,	4360.96,	-1.00,	1,	1,	3,	4,	1,	2
LOD25	, 1550.00,	4360.96,	-1.00,	1,	1,	3,	4,	1,	2
M109	, 1650.00,	4460.96,	1.00,	2,	1,	1,	1,	1,	2
TRUCK 2-1/2	, 1252.00,	4460.96,	1.00,	1,	1,	1,	1,	1,	2
#GUN SECT CHF	, 1650.00,	4460.56,	-1.00,	1,	1,	2,	4,	1,	2
GS6	, 1650.00,	4460.56,	1.00,	1,	1,	2,	4,	1,	2
GSC6	, 1650.00,	4460.56,	-1.00,	1,	1,	2,	4,	1,	2
#GUN SECT CHF1	, 1650.00,	4460.56,	-1.00,	1,	1,	2,	4,	1,	2
GSC16	, 1650.00,	4460.56,	-1.00,	1,	1,	2,	4,	1,	2
#GUN SECT CHF2	, 1650.00,	4460.56,	-1.00,	1,	1,	2,	4,	1,	2

GSC26	, 1650.00, 4460.56, -1.00, 1, 1, 2, 4, 1, 2
GDU	, 1650.00, 4460.96, 1.00, 1, 1, 1, 1, 1, 2
AIM GUNS	, 1650.00, 4460.96, 1.00, 1, 1, 1, 1, 1, 2
COLLIMATOR	, 1650.00, 4460.96, 1.00, 1, 1, 1, 1, 1, 2
LAYING GUN	, 1650.00, 4460.96, 1.00, 1, 1, 1, 1, 1, 2
AIMING STAKE	, 1650.00, 4460.96, 1.00, 1, 1, 1, 1, 1, 2
AIMING CIRCLE	, 1650.00, 4460.96, 2.00, 1, 1, 1, 1, 1, 2
DR6	, 1650.00, 4460.96, 1.00, 1, 1, 6, 4, 1, 2
#GUNNER	, 1650.00, 4460.96, -1.00, 1, 1, 4, 4, 1, 2
GN6	, 1650.00, 4460.96, 1.00, 1, 1, 4, 4, 1, 2
GUN6	, 1650.00, 4460.96, -1.00, 1, 1, 4, 4, 1, 2
#GUNNER1	, 1650.00, 4460.96, -1.00, 1, 1, 4, 4, 1, 2
GUN16	, 1650.00, 4460.96, -1.00, 1, 1, 4, 4, 1, 2
#LOADER	, 1650.00, 4460.96, -1.00, 1, 1, 3, 4, 1, 2
LD6	, 1650.00, 4460.96, 1.00, 1, 1, 3, 4, 1, 2
LOD6	, 1650.00, 4460.96, -1.00, 1, 1, 3, 4, 1, 2
#LOADER1	, 1650.00, 4460.96, -1.00, 1, 1, 3, 4, 1, 2
LOD16	, 1650.00, 4460.96, -1.00, 1, 1, 3, 4, 1, 2
#LOADER2	, 1650.00, 4460.96, -1.00, 1, 1, 3, 4, 1, 2
LOD26	, 1650.00, 4460.96, -1.00, 1, 1, 3, 4, 1, 2
M109	, 1750.00, 4410.96, 1.00, 2, 1, 1, 1, 1, 2
TRUCK 2-1/2	, 1752.00, 4010.96, 1.00, 1, 1, 1, 1, 1, 2
#GUN SECT CHF2	, 1750.00, 4410.56, -1.00, 1, 1, 2, 4, 1, 2
GSC27	, 1750.00, 4410.56, -1.00, 1, 1, 2, 4, 1, 2
#GUN SECT CHF1	, 1750.00, 4410.56, -1.00, 1, 1, 2, 4, 1, 2
GSC17	, 1750.00, 4410.56, -1.00, 1, 1, 2, 4, 1, 2
#GUN SECT CHF	, 1750.00, 4410.56, -1.00, 1, 1, 2, 4, 1, 2
GS7	, 1750.00, 4410.56, 1.00, 1, 1, 2, 4, 1, 2
GSC7	, 1750.00, 4410.56, -1.00, 1, 1, 2, 4, 1, 2
GDU	, 1750.00, 4410.96, 1.00, 1, 1, 1, 1, 1, 2
AIM GUNS	, 1750.00, 4410.96, 1.00, 1, 1, 1, 1, 1, 2
COLLIMATOR	, 1750.00, 4410.96, 1.00, 1, 1, 1, 1, 1, 2
LAYING GUN	, 1750.00, 4410.96, 1.00, 1, 1, 1, 1, 1, 2
AIMING STAKE	, 1750.00, 4410.96, 1.00, 1, 1, 1, 1, 1, 2
AIMING CIRCLE	, 1750.00, 4410.96, 2.00, 1, 1, 1, 1, 1, 2
DR7	, 1750.00, 4410.96, 1.00, 1, 1, 6, 4, 1, 2
#GUNNER	, 1750.00, 4410.96, -1.00, 1, 1, 4, 4, 1, 2
GN7	, 1750.00, 4410.96, 1.00, 1, 1, 4, 4, 1, 2
GUN7	, 1750.00, 4410.96, -1.00, 1, 1, 4, 4, 1, 2
#GUNNER1	, 1750.00, 4410.96, -1.00, 1, 1, 4, 4, 1, 2
GUN17	, 1750.00, 4410.96, -1.00, 1, 1, 4, 4, 1, 2
#LOADER	, 1750.00, 4410.96, -1.00, 1, 1, 3, 4, 1, 2
LD7	, 1750.00, 4410.96, 1.00, 1, 1, 3, 4, 1, 2
LOD7	, 1750.00, 4410.96, -1.00, 1, 1, 3, 4, 1, 2
#LOADER1	, 1750.00, 4410.96, -1.00, 1, 1, 3, 4, 1, 2
LOD17	, 1750.00, 4410.96, -1.00, 1, 1, 3, 4, 1, 2
#LOADER2	, 1750.00, 4410.96, -1.00, 1, 1, 3, 4, 1, 2
LOD27	, 1750.00, 4410.96, -1.00, 1, 1, 3, 4, 1, 2
M109	, 1900.00, 4510.96, 1.00, 2, 1, 1, 1, 1, 2
TRUCK 2-1/2	, 1902.00, 4110.96, 1.00, 1, 1, 1, 1, 1, 2
#LOADER	, 1902.00, 4510.96, -1.00, 1, 1, 3, 4, 1, 2
LD8	, 1902.00, 4510.96, 1.00, 1, 1, 3, 4, 1, 2
LOD8	, 1902.00, 4510.96, -1.00, 1, 1, 3, 4, 1, 2
#LOADER1	, 1902.00, 4510.96, -1.00, 1, 1, 3, 4, 1, 2
LOD18	, 1902.00, 4510.96, -1.00, 1, 1, 3, 4, 1, 2
#LOADER2	, 1902.00, 4510.96, -1.00, 1, 1, 3, 4, 1, 2
LOD28	, 1902.00, 4510.96, -1.00, 1, 1, 3, 4, 1, 2
#GUN SECT CHF	, 1900.00, 4510.56, -1.00, 1, 1, 2, 4, 1, 2
GS8	, 1900.00, 4510.56, 1.00, 1, 1, 2, 4, 1, 2
GSC8	, 1900.00, 4510.56, -1.00, 1, 1, 2, 4, 1, 2
#GUN SECT CHF1	, 1900.00, 4510.56, -1.00, 1, 1, 2, 4, 1, 2
GSC18	, 1900.00, 4510.56, -1.00, 1, 1, 2, 4, 1, 2
#GUN SECT CHF2	, 1900.00, 4510.56, -1.00, 1, 1, 2, 4, 1, 2
GSC28	, 1900.00, 4510.56, -1.00, 1, 1, 2, 4, 1, 2

GDU	, 1900.00,	4510.96,	1.00,	1,	1,	1,	1,	1,	2
AIM GUNS	, 1900.00,	4510.96,	1.00,	1,	1,	1,	1,	1,	2
COLLIMATOR	, 1900.00,	4510.96,	1.00,	1,	1,	1,	1,	1,	2
LAYING GUN	, 1900.00,	4510.96,	1.00,	1,	1,	1,	1,	1,	2
AIMING STAKE	, 1900.00,	4510.96,	1.00,	1,	1,	1,	1,	1,	2
AIMING CIRCLE	, 1900.00,	4510.96,	2.00,	1,	1,	1,	1,	1,	2
DR8	, 1900.00,	4510.96,	1.00,	1,	1,	6,	4,	1,	2
#GUNNER	, 1900.00,	4510.96,	-1.00,	1,	1,	4,	4,	1,	2
GN8	, 1900.00,	4510.96,	1.00,	1,	1,	4,	4,	1,	2
GUN8	, 1900.00,	4510.96,	-1.00,	1,	1,	4,	4,	1,	2
#GUNNER1	, 1900.00,	4510.96,	-1.00,	1,	1,	4,	4,	1,	2
GUN18	, 1900.00,	4510.96,	-1.00,	1,	1,	4,	4,	1,	2
BTRY PHONE	, 3050.00,	3997.28,	1.00,	1,	1,	1,	1,	1,	2
BTRY PHONE	, 1250.00,	3997.28,	2.00,	1,	1,	1,	1,	1,	2
BTRY PRC-68	, 1250.00,	3997.28,	1.00,	1,	1,	1,	1,	1,	2
BTRY VRC-46	, 1250.00,	3997.28,	1.00,	1,	1,	1,	1,	1,	2
BTRY VRC-46	, 3050.00,	3997.28,	1.00,	1,	1,	1,	1,	1,	2
BTRY GRC-160	, 3050.00,	3997.28,	1.00,	1,	1,	1,	1,	1,	2
BTRY CO	, 3050.00,	3997.28,	1.00,	1,	1,	7,	1,	1,	2
\$2,1,.25									
1ST SGT	, 1250.00,	3997.28,	1.00,	1,	1,	7,	1,	1,	2
\$2,1,.25									
NBC NCO	, 1250.00,	3997.28,	1.00,	1,	1,	7,	1,	1,	2
\$2,1,.25									
BTRY PERSONNEL	, 1250.00,	3997.28,	7.00,	1,	1,	7,	1,	1,	2
\$2,1,.25									
PLT DRIVERS	, 3050.00,	3997.28,	1.00,	1,	1,	1,	1,	1,	2
\$2,1,.25									
M577A1	, 256.83,	4100.29,	1.00,	1,	1,	1,	1,	1,	2
FDC M577A1	, 256.83,	4100.29,	-1.00,	1,	1,	1,	1,	1,	2
BCS	, 256.83,	4100.29,	1.00,	1,	1,	1,	1,	1,	2
PLOTTING EQP	, 256.83,	4100.29,	1.00,	1,	1,	1,	1,	1,	2
FDC COMMO	, 256.83,	4100.29,	-1.00,	1,	1,	1,	1,	1,	2
FDC VRC-46	, 256.83,	4100.29,	3.00,	1,	1,	1,	1,	1,	2
FDC PRC-68	, 256.83,	4100.29,	1.00,	1,	1,	1,	1,	1,	2
FDC PHONE	, 256.83,	4100.29,	4.00,	1,	1,	1,	1,	1,	2
PLT PRC-68	, 256.83,	4100.29,	1.00,	1,	1,	1,	1,	1,	2
PLT VRC-46	, 256.83,	4100.29,	1.00,	1,	1,	1,	1,	1,	2
CHF FD COMPUTER	, 256.83,	4100.29,	1.00,	1,	1,	5,	5,	4,	2
FA FD CREW	, 256.83,	4100.29,	4.00,	1,	1,	1,	5,	4,	2
M577 DRIVER	, 256.83,	4100.29,	1.00,	1,	1,	1,	5,	4,	2
PLT LDR	, 256.83,	4100.29,	1.00,	1,	1,	1,	5,	4,	2
PLT SGT	, 256.83,	4100.29,	1.00,	1,	1,	1,	5,	4,	2
PLT DRIVERS	, 256.83,	4100.29,	2.00,	1,	1,	1,	5,	4,	2
FDC RADIO	, 256.84,	4100.27,	-1.00,	1,	1,	1,	1,	1,	2
FDO CALCULATOR	, 256.84,	4100.27,	-1.00,	1,	1,	5,	1,	1,	2
FA FD CREW COMPTR	, 256.84,	4100.27,	-1.00,	1,	1,	10,	1,	1,	2
FDO MANUAL	, 256.84,	4100.27,	-1.00,	1,	1,	9,	1,	1,	2
FA FD CREW MANUAL	, 256.84,	4100.27,	-1.00,	1,	1,	10,	1,	1,	2
AUTHORITY	, 256.84,	4100.27,	-1.00,	1,	1,	7,	1,	1,	2
M577A1	, 1707.01,	4128.97,	1.00,	1,	1,	1,	1,	1,	2
FDC M577A1	, 1707.01,	4128.97,	-1.00,	1,	1,	1,	1,	1,	2
BCS	, 1707.01,	4128.97,	1.00,	1,	1,	1,	1,	1,	2
PLOTTING EQP	, 1707.01,	4128.97,	1.00,	1,	1,	1,	1,	1,	2
FDC COMMO	, 1707.01,	4128.97,	-1.00,	1,	1,	1,	1,	1,	2
FDC VRC-46	, 1707.01,	4128.97,	3.00,	1,	1,	1,	1,	1,	2
FDC PRC-68	, 1707.01,	4128.97,	1.00,	1,	1,	1,	1,	1,	2
FDC PHONE	, 1707.01,	4128.97,	4.00,	1,	1,	1,	1,	1,	2
PLT PRC-68	, 1707.01,	4128.97,	1.00,	1,	1,	1,	1,	1,	2
PLT VRC-46	, 1707.01,	4128.97,	1.00,	1,	1,	1,	1,	1,	2
FDO	, 1707.01,	4128.97,	1.00,	1,	1,	5,	5,	4,	2
CHF FD COMPUTER	, 1707.01,	4128.97,	1.00,	1,	1,	5,	5,	4,	2
FA FD CREW	, 1707.01,	4128.97,	4.00,	1,	1,	1,	5,	4,	2
M577 DRIVER	, 1707.01,	4128.97,	1.00,	1,	1,	1,	5,	4,	2

PLT LDR	,	1707.01,	4128.97,	1.00,	1,	1,	1,	5,	4,	2
PLT SGT	,	1707.01,	4128.97,	1.00,	1,	1,	1,	5,	4,	2
PLT DRIVERS	,	1707.01,	4128.97,	2.00,	1,	1,	1,	5,	4,	2
FDC RADIO	,	1707.02,	4128.94,	-1.00,	1,	1,	1,	1,	1,	2
FDO CALCULATOR	,	1707.02,	4128.94,	-1.00,	1,	1,	5,	1,	1,	2
FA FD CREW COMPTR	,	1707.02,	4128.94,	-1.00,	1,	1,	10,	1,	1,	2
FDO MANUAL	,	1707.02,	4128.94,	-1.00,	1,	1,	9,	1,	1,	2
FA FD CREW MANUAL	,	1707.02,	4128.94,	-1.00,	1,	1,	10,	1,	1,	2
AUTHORITY	,	1707.02,	4128.94,	-1.00,	1,	1,	7,	1,	1,	2
FDC COMPUTER	,	256.83,	4100.29,	-1.00,	1,	1,	1,	1,	1,	2
FDC COMPUTER	,	1707.01,	4128.97,	-1.00,	1,	1,	1,	1,	1,	2
M577A1	,	583.37,	2974.62,	2.00,	1,	1,	1,	1,	1,	2

END

LINKS

#REPAIR LINKS

SP FA AUTO MECH,4.,100,4.

\$SVC TM CHIEF

\$T,0.

\$E,1.

FA WEAPONS MECH,2.,100,2.

\$SVC TM CHIEF

\$T,0.

\$E,.7

SP FA SYSTEM MECH,1.,100,4.

\$SVC TM CHIEF

\$T,0.

\$E,.7

#REPAIR SUBCHAINS

MED,2.

\$MECH

\$T,0.

\$E,1.

LIGHT,2.

\$CREW

\$T,0.

\$E,1.

M109,8.,100,8.

GUN1,1.,100,1.

\$GN1

\$T,0.

\$E,1.

GUN2,1.,100,1.

\$GN2

\$T,0.

\$E,1.

GUN3,1.,100,1.

\$GN3

\$T,0.

\$E,1.

GUN4,1.,100,1.

\$GN4

\$T,0.

\$E,1.

GUN5,1.,100,1.

\$GN5

\$T,0.

\$E,1.

GUN6,1.,100,1.

\$GN6

\$T,0.

\$E,1.

GUN7,1.,100,1.

\$GN7

\$T,0.

```

$E,1.
GUN8,1.,100,1.
$GN8
$T,0.
$E,1.
#GUNNER,8.,100,8.
#$GN1,GN2,GN3,GN4,GN5,GN6,GN7,GN8,GS1,GS2,GS3,GS4,GS5,GS6,GS7,GS8
#$T,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.
#$E,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.
GSC1,1.,100,1.
$GS1
$T,0.
$E,1.
GSC2,1.,100,1.
$GS2
$T,0.
$E,1.
GSC3,1.,100,1.
$GS3
$T,0.
$E,1.
GSC4,1.,100,1.
$GS4
$T,0.
$E,1.
GSC5,1.,100,1.
$GS5
$T,0.
$E,1.
GSC6,1.,100,1.
$GS6
$T,0.
$E,1.
GSC7,1.,100,1.
$GS7
$T,0.
$E,1.
GSC8,1.,100,1.
$GS8
$T,0.
$E,1.
#GUN SECT CHF,8.,100,8.
#$GS1,GS2,GS3,GS4,GS5,GS6,GS7,GS8,GN1,GN2,GN3,GN4,GN5,GN6,GN7,GN8
#$T,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.
#$E,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.
LOD1,1.,100,1.
$LD1
$T,0.
$E,1.
LOD2,1.,100,1.
$LD2
$T,0.
$E,1.
LOD3,1.,100,1.
$LD3
$T,0.
$E,1.
LOD4,1.,100,1.
$LD4
$T,0.
$E,1.
LOD5,1.,100,1.
$LD5
$T,0.

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$E,1.
LOD6,1.,100,1.
$LD6
$T,0.
$E,1.
LOD7,1.,100,1.
$LD7
$T,0.
$E,1.
LOD8,1.,100,1.
$LD8
$T,0.
$E,1.
#LOADER,8.,100,8.
#$LD1,LD2,LD3,LD4,LD5,LD6,LD7,LD8,DRIVER
#$T,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.
#$E,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.
GSC11,1.,70,1.
$GS1
$T,0.
$E,1.
GSC12,1.,70,1.
$GS2
$T,0.
$E,1.
GSC13,1.,70,1.
$GS3
$T,0.
$E,1.
GSC14,1.,70,1.
$GS4
$T,0.
$E,1.
GSC15,1.,70,1.
$GS5
$T,0.
$E,1.
GSC16,1.,70,1.
$GS6
$T,0.
$E,1.
GSC17,1.,70,1.
$GS7
$T,0.
$E,1.
GSC18,1.,70,1.
$GS8
$T,0.
$E,1.
#GUN SECT CHF1,8.,70,8.
#$GS1,GS2,GS3,GS4,GS5,GS6,GS7,GS8
#$T,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.
#$E,1.,1.,1.,1.,1.,1.,1.,1.,1.,1.
GSC21,1.,50,1.
$GS1
$T,0.
$E,1.
GSC22,1.,50,1.
$GS2
$T,0.
$E,1.
GSC23,1.,50,1.
$GS3
$T,0.

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$E,1.
GSC24,1.,50,1.
$GS4
$T,0.
$E,1.
GSC25,1.,50,1.
$GS5
$T,0.
$E,1.
GSC26,1.,50,1.
$GS6
$T,0.
$E,1.
GSC27,1.,50,1.
$GS7
$T,0.
$E,1.
GSC28,1.,50,1.
$GS8
$T,0.
$E,1.
#GUN SECT CHF2,8.,50,8.
#GSC1,GSC2,GSC3,GSC4,GSC5,GSC6,GSC7,GSC8
#$T,0.,0.,0.,0.,0.,0.,0.,0.
#$E,1.,1.,1.,1.,1.,1.,1.,1.
GUN11,1.,70,1.
$GN1
$T,0.
$E,1.
GUN12,1.,70,1.
$GN2
$T,0.
$E,1.
GUN13,1.,70,1.
$GN3
$T,0.
$E,1.
GUN14,1.,70,1.
$GN4
$T,0.
$E,1.
GUN15,1.,70,1.
$GN5
$T,0.
$E,1.
GUN16,1.,70,1.
$GN6
$T,0.
$E,1.
GUN17,1.,70,1.
$GN7
$T,0.
$E,1.
GUN18,1.,70,1.
$GN8
$T,0.
$E,1.
#GUNNER1,8.,70,8.
#$GN1,GN2,GN3,GN4,GN5,GN6,GN7,GN8
#$T,0.,0.,0.,0.,0.,0.,0.,0.
#$E,1.,1.,1.,1.,1.,1.,1.,1.
LOD11,1.,50,1.
$LD1
$T,0.

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$E,1.
LOD12,1.,50,1.
$LD2
$T,0.
$E,1.
LOD13,1.,50,1.
$LD3
$T,0.
$E,1.
LOD14,1.,50,1.
$LD3
$T,0.
$E,1.
LOD15,1.,50,1.
$LD5
$T,0.
$E,1.
LOD16,1.,50,1.
$LD6
$T,0.
$E,1.
LOD17,1.,50,1.
$LD7
$T,0.
$E,1.
LOD18,1.,50,1.
$LD8
$T,0.
$E,1.
#LOADER1,8.,50,8.
#$LD1,LD2,LD3,LD4,LD5,LD6,LD7,LD8
#$T,0.,0.,0.,0.,0.,0.,0.,0.
#$E,1.,1.,1.,1.,1.,1.,1.,1.
LOD21,1.,30,1.
$LD1
$T,0.
$E,1.
LOD22,1.,30,1.
$LD2
$T,0.
$E,1.
LOD23,1.,30,1.
$LD3
$T,0.
$E,1.
LOD24,1.,30,1.
$LD4
$T,0.
$E,1.
LOD25,1.,30,1.
$LD5
$T,0.
$E,1.
LOD26,1.,30,1.
$LD6
$T,0.
$E,1.
LOD27,1.,30,1.
$LD7
$T,0.
$E,1.
LOD28,1.,30,1.
$LD8
$T,0.

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```

$E,1.
#LOADER2,8.,30,8.
#$LD1,LD2,LD3,LD4,LD5,LD6,LD7,LD8
#$T,0.,0.,0.,0.,0.,0.,0.,0.
#$E,1.,1.,1.,1.,1.,1.,1.,1.
DR1,1.,30,1.
DR2,1.,30,1.
$DR2
$T,0.
$E,1.
DR3,1.,30,1.
$DR3
$T,0.
$E,1.
DR4,1.,30,1.
$DR4
$T,0.
$E,1.
DR5,1.,30,1.
$DR5
$T,0.
$E,1.
DR6,1.,30,1.
$DR6
$T,0.
$E,1.
DR7,1.,30,1.
$DR7
$T,0.
$E,1.
DR8,1.,30,1.
$DR8
$T,0.
$E,1.
#DRIVER,8.,30,8.
#$DR1,DR2,DR3,DR4,DR5,DR6,DR7,DR8
#$T,0.,0.,0.,0.,0.,0.,0.,0.
#$E,1.,1.,1.,1.,1.,1.,1.
AIM GUNS,8.,100,8.
$COLLIMATOR,AIMING STAKE
$T,0.,0.
$E,1.0,.50#CHANGED FROM .75 TO .50
LAYING GUN,8.,100,8.
$AIMING CIRCLE#MANUAL BACKUP
$T,0.
$E,.5
GDU,8.,100,8.
FDC COMPUTER,1.,100,2.
$BCS
$T,0.
$E,1.
FDO CALCULATOR,1.,100,1.
$FDO,PLT LDR,PLT SGT,CHF FD COMPUTER,GS1,GS2,GS3,GS4,GS5,GS6,GS7,GS8
$T,0.,5.,5.,0.,15.,15.,15.,15.,15.,15.,15.
$E,1.,1.,1.,1.,5.,5.,5.,5.,5.,5.,5
FA FD CREW COMPTR,1.,100,1.
$FA FD CREW,FDO,PLT LDR,PLT SGT,CHF FD COMPUTER,GS1,GS2,GS3,GS4,GS5,GS6,GS7,GS8
$T,0.,0.,5.,5.,0.,15.,15.,15.,15.,15.,15.,15.
$E,1.,1.,1.,1.,1.,7.,7.,7.,7.,7.,7.,7
GUN COMMO VOICE,8.,100,8.
$M,90
GUN COMMO DATA,8.,100,8.
$M,50
NO COMMO,1.,40,1.

```

\$M,40
 \$DR1
 \$T,0.
 \$E,1.
 \$M,40
 FDC COMMO,1.,80,1.
 \$FDC PHONE,FDC PRC-68
 \$T,0.,0.
 \$E,1.,.8
 FDO MANUAL,1.,80,2.
 \$FDO,PLT LDR,PLT SGT,CHF FD COMPUTER,GS1
 \$T,0.,5.,5.,0.,15.
 \$E,1.,1.,1.,1.,.5
 FA FD CREW MANUAL,3.,80,3.
 \$M,1.,0
 \$FA FD CREW,FDO,PLT LDR,PLT SGT,CHF FD COMPUTER
 \$T,0.,0.,5.,5.,0.
 \$E,1.,1.,1.,1.,1.
 FDC RADIO,1.,75,1.
 \$M,0.,0
 \$FDC VRC-46,PLT VRC-46
 \$T,0.,0.
 \$E,1.,1.
 AUTHORITY,1.,75,1.
 \$M,0.,0
 \$FDC CREW,PLT CREW
 \$T,0.,0.
 \$E,1.,1.
 \$M,0.,65
 TRUCK 2-1/2,4.,100,8.
 #ONLY NEED 1/2 AT EACH LOCATION
 \$M,0.,50
 FDC M577A1,2.,100,2.
 \$M,0.,50
 \$M577A1
 \$T,0.
 \$E,1.
 END
 SUBCHAIN
 *41,GDU,FDC COMPUTER,FDO CALCULATOR,FA FD CREW COMPTR
 *42,FDC COMMO,FDO MANUAL,FA FD CREW MANUAL
 *43,FDC RADIO,AUTHORITY
 *44,AIM GUNS,LAYING GUN
 *45,GUN COMMO VOICE,GUN COMMO DATA
 #*6,GUN SECT CHF,GUNNER,LOADER
 #*7,GUN SECT CHF1,GUNNER1
 #*8,GUN SECT CHF2,LOADER1
 #*9,LOADER2,DRIVER
 *6,GSC1,GUN1,LOD1
 *10,GSC2,GUN2,LOD2
 *14,GSC3,GUN3,LOD3
 *18,GSC4,GUN4,LOD4
 *22,GSC5,GUN5,LOD5
 *26,GSC6,GUN6,LOD6
 *30,GSC7,GUN7,LOD7
 *1,GSC8,GUN8,LOD8
 *7,GSC11,GUN11
 *11,GSC12,GUN12
 *15,GSC13,GUN13
 *19,GSC14,GUN14
 *23,GSC15,GUN15
 *27,GSC16,GUN16
 *31,GSC17,GUN17
 *2,GSC18,GUN18


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*8,GSC21,LOD11
*12,GSC22,LOD12
*16,GSC23,LOD13
*20,GSC24,LOD14
*24,GSC25,LOD15
*28,GSC26,LOD16
*32,GSC27,LOD17
*3,GSC28,LOD18
*9,LOD21,DR1
*13,LOD22,DR2
*17,LOD23,DR3
*21,LOD24,DR4
*25,LOD25,DR5
*29,LOD26,DR6
*33,LOD27,DR7
*4,LOD28,DR8
END
ORLINK
+1,*41,*42,*43#FDC ORLINK
+2,*6,*7,*8,*9#CREW ORLINK
+3,*45, NO COMMO#GUN COMMUNICATIONS ORLINK
+4,*10,*11,*12,*13
+5,*14,*15,*16,*17
+6,*18,*19,*20,*21
+7,*22,*23,*24,*25
+8,*26,*27,*28,*29
+9,*30,*31,*32,*33
+10,*1,*2,*3,*4
END
COMPOUND LINK
!FIRING
+2,.125
+4,.125
+5,.125
+6,.125
+7,.125
+8,.125
+9,.125
+10,.125
END
CHAINS
!FIRING,M109,TRUCK 2-1/2,FDC M577A1
$T,0.,20000.
END
RECONSTITUTION EVENTS
420.,660.,900.,2100.,2580.,2820.,3540.,4020.,4260.,4980.,5460.,
$5700.,6420.,7860.,8340.,8580.,9300.,9780.,10020.,15840.
END
OUTPUT
SUMMARY,GUN SECTION CHFS,GUNNERS,DRIVERS,LOADERS,PERSONNEL,EQP
LETHALITY,OFF
RANDOM NUMBER,OFF
END
REPLICATION
50
END
# put degradation and heat stress here
HEADING
M109 - No Chemical Threat - A12D2 - No work/rest
END
HEAT STRESS
T,0.,420.
$T,31.1
$H,46.4

```

\$W,2.9
T,420.,660.
\$T,35.6
\$H,34.1
\$W,4.6
T,660.,900.
\$T,40.9
\$H,20.26
\$W,6.4
T,900.,1140.
\$T,39.1
\$H,21.4
\$W,6.1
T,1140.,1380.
\$T,34.5
\$H,39.19
\$W,3.3
T,1380.,1440.
\$T,31.1
\$H,46.4
\$W,2.9
R,
M,125.
\$SP FA AUTO MECH
\$FA WEAPONS MECH
\$SP FA SYSTEM MECH
\$MED
\$LIGHT
M,132.75
\$DR1
\$DR2
\$DR3
\$DR4
\$DR5
\$DR6
\$DR7
\$DR8
M,250.
\$GUN1
\$GUN2
\$GUN3
\$GUN4
\$GUN5
\$GUN6
\$GUN7
\$GUN8
M,313.5
\$GUN11
\$GUN12
\$GUN13
\$GUN14
\$GUN15
\$GUN16
\$GUN17
\$GUN18
M,250.
\$GSC1
\$GSC2
\$GSC3
\$GSC4
\$GSC5
\$GSC6
\$GSC7
\$GSC8

M, 313.5
\$GSC11
\$GSC12
\$GSC13
\$GSC14
\$GSC15
\$GSC16
\$GSC17
\$GSC18
M, 213.75
\$GSC21
\$GSC22
\$GSC23
\$GSC24
\$GSC25
\$GSC26
\$GSC27
\$GSC28
M, 425.
\$LOD1
\$LOD2
\$LOD3
\$LOD4
\$LOD5
\$LOD6
\$LOD7
\$LOD8
M, 301.25
\$LOD11
\$LOD12
\$LOD13
\$LOD14
\$LOD15
\$LOD16
\$LOD17
\$LOD18
M, 222.75
\$LOD21
\$LOD22
\$LOD23
\$LOD24
\$LOD25
\$LOD26
\$LOD27
\$LOD28
C, 4, 1.68
I, 4, .21
C, 2, 1.13
I, 2, .43
GC, 4, .255
GC, 2, .26
GI, 4, .49
GI, 2, .38
S, 36.5
D, 2.
E, 0.
A, 12.
END
DEGRADATION
2, 1, 1.
2, 2, 1.
2, 3, 1.
2, 4, 1.
2, 5, 1.

2,6,1.
 2,7,1.
 2,8,1.
 2,9,1.
 2,10,1.
 4,1,.7# EVERYONE ELSE
 4,2,.95# GUN SECT CHF
 4,3,.7# LOADERS
 4,4,.63# GUNNERS
 4,5,.63# CHF FD COMPUTER
 4,6,.63# DRIVERS
 4,7,.95# BTRY CO,1ST SGT,NBC NCO,BTRY PERSONNEL,AUTHORITY
 4,8,1.
 4,9,.63# FDO MANUAL
 4,10,.63# FA FD CREW COMPTR,FA FD CREW MANUAL
 END
 T.K.C.
 DRIVER,1,1.
 GUN CHIEF,2,1.
 LOADER,3,1.
 GUNNER,4,1.
 FDO C,5,1.
 FIRING PLT LDR,6,1.
 BTRY CO,7,1.
 CBR PERS,8,1.
 FDO M,9,1.
 FD SPEC,10,1.
 END
 CONVENTIONAL LETHALITY DATA
 END
 INCOMING FIRE DIRECTION
 270
 END
 #VOLLEY
 #WPN52,5760.,250.,4000.,0.,12,90.,400.
 #WPN52,5760.,250.,4200.,0.,12,90.,400.
 #WPN52,5760.,250.,4400.,0.,12,90.,400.
 #WPN52,5760.,250.,4600.,0.,12,90.,400.
 #WPN52,5760.,1750.,4000.,0.,12,90.,400.
 #WPN52,5760.,1750.,4200.,0.,12,90.,400.
 #WPN52,5760.,1750.,4400.,0.,12,90.,400.
 #WPN52,5760.,1750.,4600.,0.,12,90.,400.
 #END
 MOPP
 ROUND YES,15.
 END
 TOXIC LETHALITY DATA
 END
 GO
 STOP